AD-A104 757 BELL HELICOPTER TEXTRON FORT WORTH TX F/G 13/12

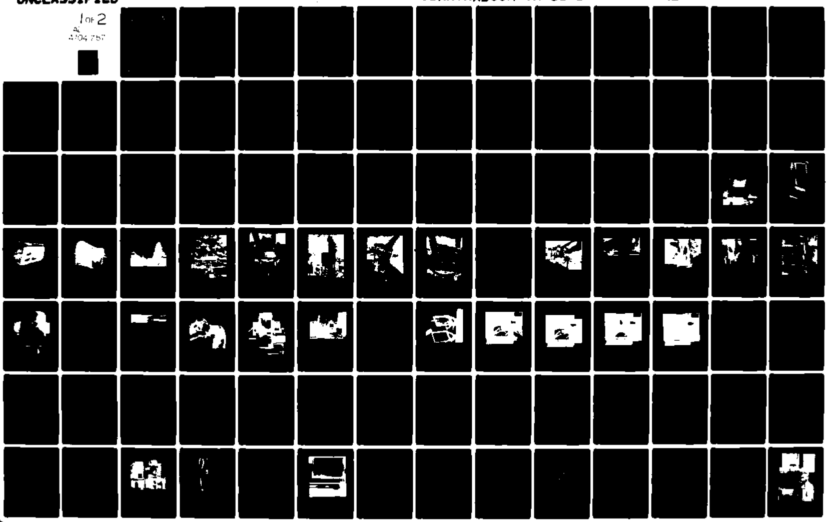
INVESTIGATION OF THE STRUCTURAL DEGRADATION AND PERSONNEL HAZAR--ETC(U)

AUG 81 R J SCHILTZ DAAK51-79-C-0009

UNCLASSIFIED USAAVRADCOM-TR-81-D-16 NL

1 OF 2

AD A104 757



12

USAAVRADCOM-TR-81-D-16

INVESTIGATION OF THE STRUCTURAL DEGRADATION AND PERSONNEL HAZARDS RESULTING FROM HELICOPTER COMPOSITE STRUCTURES EXPOSED TO FIRES AND/OR EXPLOSIONS

R. J. Shiltz, Jr.
BELL HELICOPTER TEXTRON
P.O. Box 482
Fort Worth, Tex. 76101

August 1981

Final Report for Period March 1979 - December 1980

Approved for public release;
distribution unlimited.

Prepared for

APPLIED TECHNOLOGY LABORATORY
U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)
Fort Eustis, Va. 23604

APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report presents the results of an investigation of the structural degradation and personnel hazards resulting from helicopter composite structures exposed to fires and/or explosions. The following primary objectives were satisfied during the course of this effort. A technology survey was conducted to assess the state of the art of problems related to the structural degradation and personnel hazards resulting from the exposure of helicopter composite structures to incendiary ballistic projectiles, in-flight fires, and postcrash fires. Ballistic tests, smoke and toxicity tests, and structural degradation tests were conducted and the data were evaluated. Design criteria were established based on the technology survey and testing. An addititional objective was to identify and select an existing computer program to simulate the structural degradation and personnel hazards resulting from helicopter composite structures exposed to fire. The Dayton Aircraft Cabin Fire (DACFIR-2) simulation computer program was selected to assess the smoke, heat, and toxic gas accumulation within an aircraft cabin subjected to fire.

William T. Alexander and Robert L. Rodgers of the Structures Technical Area, Aeronautical Technology Division, served as project engineers for this effort.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: USAAVRADCOM-TR-81-D-16
2. GOVT ACCESSION NO.: AD-A104 757
3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): INVESTIGATION OF THE STRUCTURAL DEGRADATION AND PERSONNEL HAZARDS RESULTING FROM HELICOPTER COMPOSITE STRUCTURES EXPOSED TO FIRES AND/OR EXPLOSIONS
5. TYPE OF REPORT & PERIOD COVERED: Final Report, Mar 1979 — Dec 1980
6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): R. J. Schiltz, Jr.
8. CONTRACT OR GRANT NUMBER(s): DAAK51-79-C-0009

9. PERFORMING ORGANIZATION NAME AND ADDRESS: Bell Helicopter Textron, P. O. Box 482, Fort Worth, Texas 76101
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 612209 1L162209AH76 00 257 EK

11. CONTROLLING OFFICE NAME AND ADDRESS: Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia 23604
12. REPORT DATE: Aug [illegible]81
13. NUMBER OF PAGES: 110

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

STRUCTURAL DEGRADATION, SMOKE, TOXICITY, COMPOSITE MATERIALS, HELICOPTERS, ROTARY WING AIRCRAFT, EPOXY, KEVLAR, GRAPHITE, COMPUTER PROGRAMS, THERMAL DEGRADATION, DESIGN CRITERIA, COMPOSITE STRUCTURES, EXPLOSION EFFECTS, LITERATURE SURVEYS, TEST AND EVALUATION

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A program was undertaken to investigate the structural degradation and personnel hazards resulting from exposure of helicopter composite structures to fire and/or explosion. The program consisted of a technical survey, a test program, and an analysis phase.

A major part of the technical survey was a literature survey. In addition, organizations working in the fields of interest were contacted for information,

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

and some were visited for further, detailed discussions. The computer programs currently available for modeling enclosure fires were screened, and one was chosen for further study. The test program consisted of a series of tests on two representative helicopter structures: a sheet-stiffened, built-up door of Kevlar 49 fabric impregnated with an epoxy resin, and a honeycomb sandwich fuselage shell structure of graphite/epoxy fabric skins on a Nomex honeycomb core. The tests conducted on materials from these structures were smoke generation tests, toxicity tests, and structural degradation tests. Ballistic tests on the complete test article were conducted to determine whether the structures would ignite under HEI impact conditions.

Based on the survey and testing, design criteria for structural composite components were investigated and, when appropriate, formulated.

PREFACE

This report was prepared by Bell Helicopter Textron (BHT) under U.S. Army contract DAAK51-79-C-0009. The contract was administered under the technical direction of Mr. William T. Alexander and Mr. Robert L. Rodgers of the Applied Technology Laboratory (ATL).

Technical tasks in this program were conducted under the direction of Dr. Raymond J. Schiltz, Jr., BHT project engineer. Principal investigators at BHT were Messrs. Tom Haas, structural criteria; Bill Taylor, specimen fabrication; and Doug Blocker, structural degradation testing. In performing this effort, BHT teamed with Grumman Aerospace Corporation (GAC), Bethpage, New York. The project engineer at GAC was Mr. John Roman. Principal investigators at GAC were Dr. Vincent Volpe, surveys and computer program selection, and Mr. Robert Holden, smoke and toxicity testing.

Those at BHT and GAC wish to express their appreciation of Mr. W. T. Alexander's assistance and support in the performance of this work.

TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont)

LIST OF ILLUSTRATIONS (Cont)

LIST OF ILLUSTRATIONS (Cont)

LIST OF TABLES

1. INTRODUCTION

PROGRAM OBJECTIVES

The objective of this program was to investigate the structural degradation and personnel hazards resulting from the exposure of helicopter composite structures to incendiary ballistic projectiles, inflight fires, and post-crash fires, in order to expand current knowledge of the structural and personnel safety characteristics of these structures. An additional objective was to identify and select an existing computer program to simulate the structural degradation and personnel hazards resulting from helicopter composite structures exposed to fire. The selected computer program will be demonstrated.

PROGRAM DEFINITION

The program is divided into the following three major tasks:

TASK I - TECHNOLOGY SURVEY

- Literature Survey
- Organization Survey
- Government Briefing

TASK II - TEST AND EVALUATION

- Design Consultation
- Ballistic Tests
- Smoke and Toxicity Tests
- Structural Degradation Tests
- Documentation

TASK III - DESIGN CRITERIA

- Design Guidelines
- Computer Simulation
- Government Briefing

The completion of these tasks resulted in a better understanding of the response of composite materials when subjected to post-crash or ballistically induced fires, with the end objective of developing design criteria to enhance personnel safety under these conditions. The three tasks are briefly outlined below.

Task I. A literature survey was conducted in order to assemble published information concerning the response of structural composites to fire and/or explosion. A critical analysis of this information was conducted. A survey of the Government

and commercial laboratories active in areas relative to this study was undertaken to report on investigations not yet in the literature and to learn the newest test methods and opinions in the field. In the above surveys, special effort was directed toward evaluating existing computer programs that model enclosure fires. Based on this study, a "best" simulation program was chosen for further detailed examination. The presentation of a briefing at ATL and submittal of an interim report concluded Task I. The interim report is included in this report as Section 2.

Task II. A test plan was submitted for approval describing the work in Task II. The tests proposed and conducted were of three categories: ballistics tests, smoke and toxicity tests, and structural degradation tests. The results of these tests are presented in Section 3.

Task III. This task consisted of the formulation of design criteria, based on the results of Tasks I and II, for the minimization or avoidance of structural degradation and personnel hazards resulting from helicopter composite structures exposed to postcrash, inflight, or HEI-induced fire. The results of this effort are presented in Section 4. An additional portion of Task III was to acquire the computer simulation program selected in Task I and to make whatever modifications were necessary to be able to demonstrate its use on the computing terminal at ATL. This effort is presented in Section 5.

Conclusions and recommendations are presented in Section 6.

2. TECHNOLOGY SURVEY

The results of Task I were organized into an Interim Report and presented at a briefing at ATL.

SUMMARY

The intent of this Task I effort was to present a technology survey to assess the state of the art of problems related to the structural degradation and personnel hazards resulting from helicopter composite structures exposed to fire and/or explosions. This investigation is divided into a literature survey and an organization survey to establish the results to date and the status of pertinent ongoing research and development. The literature survey effort employed the most up-to-date computerized library data base search techniques in conjunction with a review of material from company files and from unpublished documents. The organization survey, which supplemented the information gathered in the literature search, included both visits and contacts made with Government, industry, and academic personnel actively engaged in the field. The available literature applicable to the present program has been located, reviewed, and cataloged under five categories for easy access.

LITERATURE SURVEY

Survey Objective

The survey of documentation on structural degradation and personnel hazards resulting from helicopter composite structures exposed to fire and/or explosions had five objectives. The goals were to search the existing information concerning:

1. The effects on personnel from the hazards of fire, toxicity, and smoke generated from helicopter composite structure exposed to inflight fires and postcrash fires.

2. Fire resistance of aircraft composite structures; use of resin additives and structural degradation characteristics.

3. Analytical techniques and computer programs pertinent to the simulation of the structural degradation and personnel hazards resulting from helicopter composite structure exposed to inflight fires and postcrash fires.

4. Helicopter cockpit and cabin structural composite materials and the various types of construction.

5. Fire hazards resulting from material fragmentation due to ballistic damage.

Survey Methodology

A multilevel search was conducted to locate, review, and catalog existing literature applicable to this program. The seven data bases used in the survey were:

- The National Technical Information Service (NTIS)
- The Defense Technical Information Center (DTIC)
- The Engineering Index (Compendex)
- "ORBIT" (SDC)
- "DIALOG" (Lockheed)
- Science Abstracts
- Chemical Abstracts

These data bases were surveyed in this investigation because each offered unique advantages that broadened the scope of this study. The information cataloged in the National Technical Information Service is derived from publications of the Federal, state, and local government agencies; private industry; and universities. The data available through NTIS emphasize the commercial applications. The information available from the Defense Technical Information Center is obtained from many of the same sources as NTIS; however, the emphasis is placed on military and defense use and therefore provides access to limited distribution and classified documents. The information that can be obtained from NTIS and DTIC is usually a report, a standard, or a book. The Engineering Index (Compendex) contains publications of the engineering societies such as the proceedings of conferences, journals, and magazines. The Engineering Index may also include work that is published as a magazine article and is in progress or is anticipated. The SDC ORBIT and Lockheed DIALOG data bases complement NTIS and DTIC and permit a more complete recall of the available information. The science and chemical abstracts represent a composite of the information available from industry.

The information retrieved from these data bases was supplemented by material from company files and from unpublished government and business documents. The information gathered from these data bases represents a substantial cross section of published reports and articles on flammability, toxicity, smoke generation, composite materials, analytical techniques, computer programs, design criteria, and ballistic damage.

A flow diagram of the literature search methodology used to retrieve information from the data bases and other sources is shown in Figure 1.

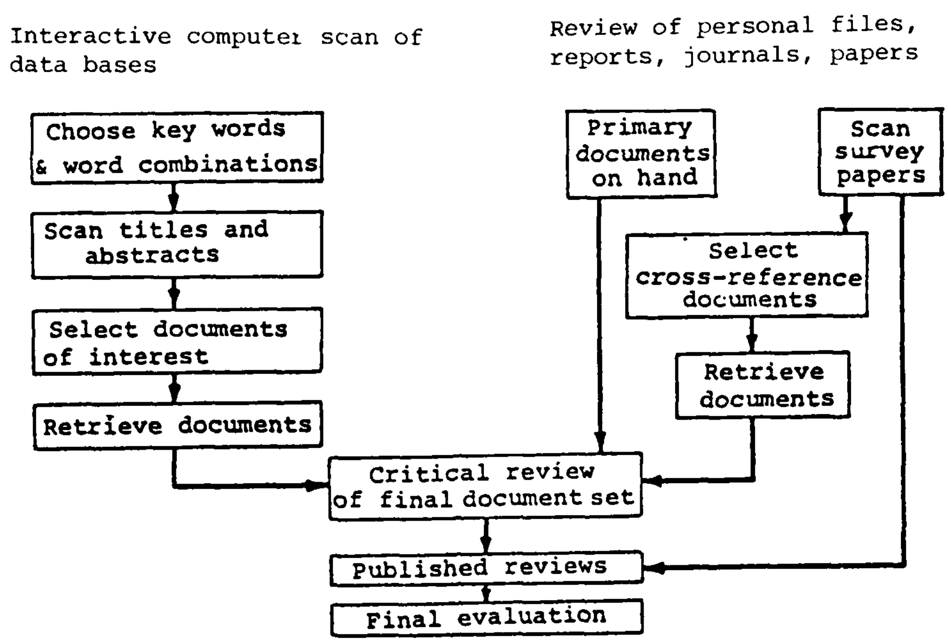


Figure 1. Literature survey methodology.

To access a data base, NTIS for example, blocks of keywords were formed and input to the system so that all information pertinent to the particular topic could be retrieved. The keyword blocks were then combined to further focus the search on the subject being surveyed until the number of documents was capable of being visually scanned. The following combinations of keywords were used during this program:

- Composite Materials and Composite Structures and Rotary Wing Vehicles and Survivability/Vulnerability
- Epoxy/Polymer and Fire/Flame/Flammability/Toxicity/Smoke and Aircraft Structures/Rotary Wing
- Resin Systems/Resin Additives/and Fire/Flammability/Toxicity/Smoke/Thermal Degradation
- Composite Materials/Composite Structures and Flammability/Toxicity/Fuel Systems
- Aircraft and Composite Materials and Fire/Flammability/Toxicity/Smoke Generation
- Composite Materials/Composite Structures and Flammability/Flames/Fires/Projectiles/Explosion Effects/Vulnerability/Survivability and Computer Programs/Computer Software
- Kevlar and Thermal Degradation/Flame/Fire/Toxicity/Flammability/Smoke
- Computer Programs and Fire/Flammability/Smoke/Toxicity/Thermal Degradation
- Composite Materials/Epoxy/Kevlar and Survivability/Vulnerability/Fire/Flame/Flammability/Smoke/Fuel Systems/Projectiles/Thermal Degradation and Rotary Wing Aircraft
- Composite Materials and Structures/Airframes and Helicopters/Army Aircraft/Rotary Wing Aircraft
- Epoxy/Resin/Composite/Graphite/Fiber/Fibre/Polymer/Fire/Fires/Flammability and Toxicity/Thermal Degradation/Smoke
- Smoke and Toxicity
- Smoke and Toxicity and Aircraft.

Document Categories

Hundreds of documents were inspected during the literature survey. Of these, 72 were subjected to a more quantitative

review. These 72 are listed in Table 1 and have been categorized under the following general subject headlines. The applicable documents, by item number, are shown in parentheses.

A. Design Guidelines and Test Methods Pertaining to

    1. Flammability (Items 1-19, 25, 26, 36-39, 41, 43-47, 56, 67, 68, and 70)

    2. Toxicity (Items 1, 13-22, 24-26, 37-39, and 53)

    3. Smoke Generation (Items 1, 4, 10, 11, 13-18, 20, 22-26, 36, 44-47, 55, and 68)

B. Fire Resistance and Degradation of Advanced Composite Materials (Items 2, 3, 6, 7, 8, 11-15, 21, 26-35, 71 and 72)

C. Analytical Techniques/Computer Programs (Items 6, 9, 10, 11, 14, 15, 18, 36-57)

D. Helicopter Cabin/Cockpit Structural Advanced Composite Materials (Items 58-69)

E. Fire Hazards Resulting from Ballistic Damage (Items 70, 71, and 72)

Analytical Techniques/Computer Programs

The reports presenting analytical techniques and/or computer programs have been grouped under Category C, comprised of Items 36 to 57 of Table 1. As the titles of these reports imply, they investigate many types of fire scenarios, such as enclosure (or room) fires, pool (or open) fires, or fully developed fires.

A summary of all the available computer programs that have been investigated for possible application to the study of helicopter composite structures exposed to fire is given in Table 2. All of the programs are modeled for fires in an enclosure such as an aircraft cabin or a room. With the exception of the Notre Dame and Jet Propulsion Laboratories (JPL) programs, these computer programs employ an empirical approach, and thus require an extensive amount of input data for the material characteristics in the particular fire under investigation for both the burning materials in the enclosure and the surrounding walls. In addition, the ventilation patterns must be known. The required input test data must be obtained for conditions very similar to those under investigation (i.e., flux levels, ventilation patterns, etc.) and therefore, one should be very careful in using available test

TABLE 1. LITERATURE SURVEY DOCUMENTS

ITEM NO.	AUTHOR	TITLE	PERFORMED BY	REPORT NUMBER (CONTRACT NUMBER)	PERFORMED FOR	DATE	AD NO.	CATEGORY
1*	Sarkos, C. P. Spurgeon, J. C. Nicholas, E. B.	Laboratory Fire Testing of Cabin Materials Used in Commercial Aircraft	FAA, NAFEC Atlantic City, NJ		Journal of Aircraft Vol. 1[illegible]	February 197[illegible]		A., Ac, A[illegible]
2*	Tewarson, A. Pion, R.	A Laboratory - Scale Test Method For the Measurement of Flammability Parameters	Factory Mutual Research Norwood, MA	FMRC Serial No. [illegible] Grant No. RF-[illegible]A Renewal	Products Research Committee Washington, D.C.	October [illegible]		A., B
3*	Tewarson, A.	Experimental Evaluation of Flammability Parameters of Polymeric Materials	Factory Mutual Research Norwood, MA	FMRC [illegible] Grant No. RI-[illegible]A Renewal	Products Research Committee Washington, D.C.	February [illegible]		A., B
4*	Wehrenberg, R.	Flammability of Plastics: The Heat is on For Large-Scale Tests		Technical Paper	Material Engineer Magazine	February [illegible]		A., A[illegible]
5*	Brown, J. R. Willert, F. P.	The Combustion of Organic Polymeric Materials. Ignition Properties	Materials Research Lab. Dept. of Defense Australia	MRL-TR-[illegible]	Defense Science and Technology Organization Melbourne, Victoria, Australia	August [illegible]	AD[illegible]	A
6*	Abbott, N. J. et al.	The Flammability, Thermal Stability, and Dyeability Properties of High Temperature Organic Fibers	Fabric Research Lab. Dedham, MA	AFML-TR-[illegible]	Air Force Materials Lab. Wright Patterson AFB OH	February [illegible]	[illegible]	[illegible]
7*	Bazinet, M. L. Di Pietro, C. Merritt, C., Jr.	Thermal Degradation Studies of Fibers and Composite Base Materials	Analytical Chemistry Group, Research & Development Command Natick, MA	NATICK/TR-[illegible] [illegible] AW[illegible] A[illegible]	Army Materials & Mechanics Research Center Watertown, MA	April [illegible]		[illegible]
[illegible]	Stanton, R. Schulman, S.	Thermal Response of Woven and Knitted Fabrics in JP-4 Fuel Fire Environment	Composite and Materials Branch, Non-metal Materials Division Wright Patterson AFB OH	AFML-[illegible]	Air Force Systems Command Wright Patterson AFB OH	October [illegible]	B00[illegible]	[illegible]
9*	Pape, R. Waterman, T. E.	Understanding and Modeling Preflashover Compartment Fires, Design of Buildings For Fire Safety	IIT Research Institute Chicago, IL	ASTM [illegible]		[illegible]		A.,
[illegible]	Wentworth, S. E. King, A. O. Shuford, R. J.	Potential for Accidental Release of Carbon/Graphite Fibers from Resin Matrix Composites as Determined by Thermogravimetric Analysis	Army Materials and Mechanics Research Center Watertown, MA	AMMRC-TR-[illegible]	U.S. Army Materiel Development & Readiness Command Alexandria, VA	January [illegible]		A., A[illegible]
[illegible]	London, A.	Hybridized Polymer Matrix Composites	Grumman Aerospace Corporation Bethpage, NY	Interim Reports NAS[illegible]	NASA, Lewis Research Ctr. Cleveland, OH	October [illegible]		A., A[illegible]

* Pertinent to this program.

TABLE 1. Continued.

ITEM No.	AUTHOR	TITLE	PERFORMED BY	REPORT NUMBER CONTRACT NUMBER	PERFORMED FOR	DATE	AD NO.	CATEGORY
12	Springer, G. S. Mashtizadeh, S. A. Keller, R. B.	Electrical Hazards Posed by Graphite Fibers	Dept. of Mechanical Engineering, University of Michigan	Technical Paper	Journal of Composite Materials, Vol. 13	July 1974		A., B
13		Kevlar 49 Data Manual	E.I. DuPont DeNemours Company	Design Guide	E.I. DuPont DeNemours & Company Wilmington, Delaware	1974		A., A2, A[illegible], [illegible]
14	Enders, J. H.	Large Scale Testing	NASA Headquarters	A Compilation of Presentations and Papers	Conference on Fire Resistant Materials (FIREMEN) Ames Research Center Moffett Field, CA	April 197[illegible]		A1, A2, A[illegible], B,
	Bricker, R. W.	737 Aircraft Flammability Testing	Johnson Space Center					
	Klinck, D.	Douglas Aircraft Fire Tests	Douglas Aircraft Company					
	Tustin, E. A.	Fire Testing In the Boeing 707 Cabin Section	Boeing Commercial Airplane Company					
	Leon, H. A.	Fire Toxicology	Ames Research Center					
	Russo, D. M.	Behavioral Technology and Its Application to Fire Toxicology Research	Southwest Foundation For Research and Education					
	Gilley, J. V. Martin, S. B. McKee, R. Pryor, G.	Smoke Toxicity Methodology	SRI International Stanford, CA					
	Anderson, R. Karch, J.	Development of Lightweight, Fire Retardant, Low Smoke, High Strength, Thermally Stable Aircraft Floor Paneling	Boeing Commercial Airplane Company					
	Gagliani, J.	Development of Fire Resistant, Low Smoke Generating, Thermally Stable End Items For Aircraft and Spacecraft	Solar Division International Harvest Company					
15	Coulbert, C.	Enclosure Fire Modeling	Jet Propulsion Laboratory					

TABLE 1. Continued

ITEM NO.	AUTHOR	TITLE	PERFORMED BY	REPORT NUMBER (CONTRACT NUMBER)	PERFORMED FOR	DATE	AD NO.	CATEGORY
[illegible]	Russo, [illegible] M.	Recent Advances In Materials Toxicology	Southwest Foundation For Research & Ed.					
	Bricker, R. W.	Flammability, Full Scale Fire Tests	Johnson Space Center					
	Supkis, D.	Status of Candidate Materials For Full-Scale Tests in the 737 Fuselage	Johnson Space Center					
	Gagliani, J.	Development of Fire-Resistant, Low Smoke Generating, Thermally Stable End Items For Commercial Aircraft and Spacecraft Using a Basic Polyimide Resin	Solar Turbines International					
	Stuart, J. W.	Global Enclosure Fire Modeling with Applications	Jet Propulsion Laboratory					
	[illegible], [illegible]	Enclosure Fire Ignition Model	Jet Propulsion Laboratory					
	Markstein, [illegible]	Large-Scale Pool Fire Test Recommendations	Jet Propulsion Laboratory	Compilation of Presentations and Papers	Conference on Fire Resistant Materials Sponsored by NASA Boeing Commercial Airplane Company Seattle, WA	March 197[illegible]		A1, A2, A3, B, [illegible]
	Stuart, [illegible]	Fuselage Ventilation Under Wind Conditions	Jet Propulsion Laboratory					
	Hara, [illegible]	A Review of Boeing Interior Materials And Fire Test Methods Development Programs	Boeing Commercial Airplane Company					
	[illegible], [illegible] A.	Advanced Resin Matrices For Composites	Ames Research Center					
	[illegible], [illegible]	A Comparative Study of the Toxicity of the Combustion Products of Cedar and a Fluorenone - Polyester Film	University of Utah					
	[illegible], [illegible] A.	Fire And Smoke Retardant Materials Development	Jet Propulsion Laboratory					
[illegible]	Anonymous	Transportation Fire Safety Summary of Regulations	Transportation Systems Center, Cambridge, MA		Dept. of Transportation Washington, D.C.	April 197[illegible]		A1, A2, A[illegible]

TABLE 1. Continued

ITEM NO.	AUTHOR	TITLE	PERFORMED BY	REPORT NUMBER (CONTRACT NUMBER)	PERFORMED FOR	DATE	AD NO.	CATEGORY
17*	Hathaway, W. T. Litant, I.	Assessment of Current U.S. Department of Transportation Fire Safety Efforts	Transportation Systems Center Cambridge, MA		Dept. of Transportation Washington, D.C.	April 1978		A1, A2, A3
18*	Birky, M. M.	Hazard Characteristics of Combustion Products in Fires - The State of the Art Review	Fire Research Center National Bureau of Standards Washington, D.C.	NBSIR 77-1234 (NASA CR-135088)	NASA Lewis Research Center Cleveland, OH	May 1977		A2, A1, A3, C
19*	Fryor, G. T. Dilley, J. V. McKee, R. L. Martin, S. B.	Behavioral Techniques in Fire Toxicology	Physical and Life Sciences Divisions SRI International Stanford, CA	Technical Paper	Presented at the California Conference on Fire Toxicology San Francisco, CA	August 1979		A2, A1
20*	Terrill, J. B. Montgomery, R. R. Reinhart, C. F.	Toxic Gases From Fires		Technical Paper	Science Magazine	June 1978		A2, A3
21*	Gilwee, W. J. Jr. Parker, J. A. Kourtides, D. A.	Oxygen Index Tests of Thermosetting Resins	Chemical Research Center NASA Ames Research Center Moffett Field, CA		Presented at the 9th Annual Technical Conference Society of Plastics Engineers, Washington, D.C.	April 1978		A2, B
22*	Ballard, R. Cagliostro, D. E. Gross, M. Ming Ta Hsu Winslow, W.	Some Pyrolysis/Toxicity Tests on Epoxy/Graphite Panels in Ames Radiant Panel System		To Be Published as NASA Report	Chemical Research Project Office, NASA Ames Research Center Moffett Field, CA	November 1979		A2, A3
23*	Brown, L. J. Jr.	Smoke Emissions from Aircraft Interior Materials At Elevated Heat Flux Levels Using Modified NBS Smoke Chamber	FAA, (NAFEC) Atlantic City, NJ	FAA-RD-79-26 (181-521-100)	Dept. of Transportation FAA Washington, D.C.	July 1979		A3
24*	Gross, D. et al.	Smoke And Gases Produced By Burning Aircraft Interior Materials	Fire Research Section National Bureau of Standards Washington, D.C.	NA-68-36 (FA66NF-AP-7)	Department of Transportation FAA Atlantic City, NJ	June 1968	N68-3-364	A3, A2
25*	Van Dolah, R. W. et al.	Review of Fire And Explosion Hazards of Flight Vehicle Combustibles	Flight Accessories Laboratory AF Systems Command	ASD-TR-61-278 (D033-616-60-8)	Flight Accessories Lab. Aeronautical Systems Div. Wright Patterson AFB OH	April 1961	262989	A3, A1, A2
26*	Atallah, S. Buccigross, H.	Investigation and Elevation of Nonflammable, Fire Retardant Materials	Arthur D. Little Cambridge MA	USAAMRDL-TR-72-52 (DAAJ02-71-C-0042)	Eustis Directorate U.S. Army Air Mobility Research And Development Lab. Ft. Eustis, VA	November 1972	906699L	B, A1, A2, A3

* Pertinent to this program.

TABLE 1. Continued

ITEM NO.	AUTHOR	TITLE	PERFORMED BY	REPORT NUMBER (CONTRACT NUMBER)	PERFORMED FOR	DATE	AD NO.	CATEGORY
27	Kallas, D. H.	Flame Resistance Properties of Glass Reinforced Plastics and Wood	U.S. Naval Applied Science Laboratory Brooklyn, NY	NASL-930-74-TM-1	Naval Ship Systems Command Washington, D.C.	October 19[illegible]7	900-022L	-
28*	Delano, C. B. Milligar, R. J.	Fire Retardant Airframe Materials Foam Composite Structures	Acurex/Aerotherm Mountain View, CA	NASA CR-137[illegible]34 (NAS2-[illegible])	NASA Washington, D.C.	March 197[illegible]		F
29*	Parts, L. Thompson, C.	Flame And Smoke Retardant Polymer Systems	Monsanto Research Corporation Dayton Laboratory	Interim Reports (N00024-7[illegible]-C-533[illegible])	Department of the Navy Washington, D.C.	April 197[illegible]	A039915 A039367	F
30*	Gehring, J.	Laboratory Evaluation of Protective Coatings Intended for Use Over Urethane Foam	Ocean City Research Corporation Ocean City, NJ	NAEC-ENG-78[illegible] (N0015[illegible]-75-C-2027)	Naval Air Engineering Ctr. Lakehurst, NJ	April 1975	A010831	F
31	Laub, B. Chu, E. Clark, K. J.	Exploratory Development of Heat Resistant & Nonflammable Fibrous Materials	Acurex/Aerotherm Mountain View, CA	AFML-TR-74-23[illegible] (F33615-7[illegible]-C-[illegible])	Air Force Materials Lab. Wright Patterson AFB OH	February 1975	A011725	F
32*	Abbot, N. J. Donovan, J. [illegible] Shoppe, M. M.	Some Mechanical Properties of Kevlar and Other Heat Resistant Nonflammable Fibers, Yarns And Fabrics.	Fabric Research Lab. Dedham, MA	AFML-TR-7[illegible] (F33615-73-C-5034)	Air Force Materials Lab. Wright Patterson AFB OH	March 197[illegible]	B006946L	F
33	Anonymous	Polyimide - Fiberglass Composites Fireproof Test	Boeing Company, Wichita, Kansas	D3-[illegible] 7[illegible]7 Aircraft	Boeing Company Wichita, KS			-
34	Springer, G. S.	Crash-Impact Fire of Fiber Reinforced Composites	Dept. of Mechanical Engineering, University of Michigan	First Annual Report to NASA Ames Research Center	NASA Ames Research Center Moffett Field, CA	August 197[illegible]		-
35*	Pering, G. A. Farrell, P. V. Springer, G. S.	Degradation of Tensile and Shear Properties of Composites Exposed to Fire or High Temperatures	Dept. of Mechanical Engineering, University of Michigan	To Be Published in the Journal of Composite Materials.	NASA Ames Research Center Moffett Field, CA	197[illegible]		-
36*	MacArthur, C. D. Reeves, J. B. Kahut, P. M.	Dayton Aircraft Cabin Fire Model Vol. I - Basic Mathematical Model II - Laboratory Test Program III - Computer Program User's Guide.	University of Dayton Research Institute Dayton, OH	FAA-RD-7[illegible]-120-[illegible] DOT-FA74WA-353[illegible]	Systems Research & Development Service, Federal Aviation Administration, Dept. of Transportation FAA Washington, D.C.	June 197[illegible]	A033682 A003683 A003989	C, A[illegible], A[illegible]
37*	MacArthur, C. D. Myers, J. F.	Dayton Aircraft Cabin Fire Model Validation - Phase I	University of Dayton Research Institute Dayton, OH	FAA-RD-78-57	Department of Transportation Washington, D.C.	March 1978		C, A[illegible], A[illegible]

* Pertinent to this program.

TABLE 1. Continued

ITEM NO.	ARTHUR	TITLE	PERFORMED BY	REPORT NUMBER (CONTRACT NUMBER)	PERFORMED FOR	DATE	AD NO.	CATEGORY
38	Emmons, H. W. Mitler, H. E. Trefethen, L. N.	Computer Fire Code III	Division of Applied Sciences Harvard University Cambridge, MA	Home Fire Project TR-25		January 1975		[illegible], A., A2
39	Mitler, H. E.	The Physical Basis for The Harvard Computer Fire Code	Division of Applied Sciences Harvard University Cambridge, MA	Home Fire Project TR-34		October 197[illegible]		[illegible], A., A2
40*	Mitler, H. E.	User's Guide For The Harvard Computer Fire Code	Division of Applied Sciences Harvard University Cambridge, MA	Home Fire Project TR-37		April 197[illegible]		
41*	Pape, R.	Computer Simulation of Full Scale Room Fire Experiments	IIT Research Institute Chicago, IL	IITRI Final Report [illegible]	Products Research Committee Washington, D.C.	March 197[illegible]		[illegible], A.
42*	Liu, [illegible] Yang, K. T.	Undsafe II - A Computer Code For Buoyant Turbulent Flow in an Enclosure With Thermal Radiation	Dept. of Aerospace and Mechanical Engineering, University of Notre Dame, Notre Dame, IN	[illegible]	National Bureau of Standards Gaithersburg, MD	July 197[illegible]		
43*	Quintiere, [illegible] McCaffrey, B. [illegible] Den Braven, K.	Experimental and Theoretical Analysis of Quasi-Steady Small-Scale Enclosure Fires	National Bureau of Standards Gaithersburg, MD	NBSIR-[illegible]	National Bureau of Standards Gaithersburg, MD	197[illegible]		[illegible], A.
44*	Smith, E. E.	Release Rate Tests And Their Application	Dept. of Chemical Engineering, Ohio State University Columbus, OH	Technical Paper	Journal of Fire And Flammability, [illegible]	July 197[illegible]		[illegible], A., A[illegible]
45*	Smith, E. E.	Evaluating Performance of Cellular Plastics in Fire Systems	Ohio State University Columbus, OH	Final Report Grant No. [illegible]	Products Research Committee Washington, D.C.	197[illegible]		[illegible], A., A[illegible]
46	Smith, E. E.	Predicting Fire Performance Using Release Rate Information	Dept. of Chemical Engineering Ohio State University Columbus, OH	Technical Paper	Proceedings of International Conference on Fire Safety, [illegible] University of San Francisco	January 197[illegible]		[illegible], A., A[illegible]
47	Waszeciak, P. H.	Large Scale Experimental Evaluation of Release Rate Model For Predicting Fire Hazards Development in Compartments Containing Cellular Plastics	Donald S. Gilmore Labs. The Upjohn Co. CT	RF-7[illegible]-[illegible]4	Products Research Committee	197[illegible]		[illegible], A., A[illegible]

* Pertinent to this program.

TABLE 1. Continued

ITEM NO.	AUTHOR	TITLE	PERFORMED BY	REPORT NUMBER (CONTRACT NUMBER	PERFORMED FOR	DATE	AD NO.	CATEGORY
48*	Harsha, P. T. Bragg, W. N. Edelman, R. B.	Preliminary Report: Improvement of a Mathematical Model of Large Open Fire	Science Applications Inc. Canoga Park, CA	SAI-79-014-CP/R	NASA Research Center Moffett Field, CA	September 1979		
49*	Babrauskas, V.	COMPF2 - A Program For Calculating Post Flashover Fire Temperatures	Center For Fire Research National Bureau of Standards Washington, D.C.	NBS Technical Note [illegible]	Department of Commerce Washington, D.C.	June [illegible]		
50*	Babrauskas, [illegible] Wickstrom, [illegible]	Thermoplastic Pool Compartment Fires	Center For Fire Research National Bureau of Standards Washington, D.C.	Technical Paper	Combustion and Flame Vol. 34, p. [illegible]	[illegible]		
51	Rosche, E. [illegible] Coulbert, [illegible]	Application of the Relative Energy Release Criteria to Enclosure Fire Testing	Jet Propulsion Lab. Pasadena, CA	JPL Publication [illegible] NASA NAS7-100	NASA Ames Research Center Moffett Field, CA	January [illegible]		
52	Coulbert, [illegible]	Enclosure Fire Hazard Analysis Using Relative Energy Release Criteria	Jet Propulsion Lab. Pasadena, CA	JPL Publication [illegible] NASA NAS7-100	NASA Ames Research Center Moffett Field, CA	December [illegible]		
53*	Cagliostro, D. E. Parker, [illegible]	Dynamic Modeling of Thermal And Gas Toxicity In Fires	Chemical Research Project Office, NASA Ames Research Center Moffett Field, CA	Technical Report	National Symposium on Fire Safety Aspects of Polymeric Materials Washington, D.C.	June [illegible]		[illegible]
54	Cagliostro, D. E. Riccitiello, S. R. Clark, K. [illegible] Shimizu, A. B.	Intumescent Coating Modeling	NASA Ames Research Center and Acrotherm Division of Acurex Corporation	Technical Paper	Journal of Fire And Flammability, [illegible]	April [illegible]		[illegible]
55*	Cagliostro, D. E.	Modeling Aerosol Losses and Clothing Effects in Fires	Chemical Research Project Office, NASA Ames Research Center Moffett Field, CA	Technical Paper	Journal of Fire And Flammability, [illegible]	[illegible]ber [illegible]		[illegible]
56	Anderson, F. H. et al.	Fire Spread Simulation Model (Flame I)	Computation Center University of North Carolina	SREC-TR-21 (DM-SR-[illegible]-3)	Office of Emergency Planning Washington, D.C.	January [illegible]		[illegible]
57	Han, L. S. Cosner, A. A.	Steady State Heat Conduction of Fiber Composite Materials	Dept. of Mechanical Engineering, Ohio State University	First Annual Report, Grant No. 78-3[illegible]40	Air Force Office of Scientific Research	August [illegible]		

* Pertinent to this program.

TABLE 1. Continued

ITEM NO.	AUTHOR	TITLE	PERFORMED BY	REPORT NUMBER CONTRACT NUMBER	PERFORMED FOR	DATE	AD NO.	CATEGORY
58*	Adams, K. M. Lucas, J. J.	Study to Investigate Design, Fabricate and Test of Low Cost Concepts for Large Hybrid Composite Helicopter Fuselage - Three Phases	Sikorsky Aircraft Stratford, CT	NASA CR-132733 NASA CR-145[illegible] NASA CR-[illegible] NASA [illegible]	NASA Langley Research Center Hampton, VA	April [illegible]	[illegible]	I
59*	Rich, M. J. et al.	Application of Composites to Helicopter Airframe and Landing Gear Structures	Sikorsky Aircraft Stratford, CT	NASA CR-12[illegible] (NAS1-1[illegible])	NASA Langley Research Center Hampton, VA	[illegible]	[illegible]	[illegible]
60*	Rich, M. J.	Investigation of Advanced Helicopter Structural Design	Sikorsky Aircraft Stratford, CT	USAAMRDL-TR-[illegible]A DAAJ[illegible]	Eustis Directorate U.S. Army Air Mobility R & D Laboratories Ft. Eustis, VA	May [illegible]	AD2[illegible]	[illegible]
61*	Swatton, S.	Study of Advanced Structural Concepts For Fuselage	Boeing Vertol Company Philadelphia, PA	USAAMRDL-TR-[illegible] DAAJ[illegible]	Eustis Directorate U.S. Army Air Mobility R & D Laboratory Ft. Eustis, VA	[illegible]	[illegible]	[illegible]
62*	Needham, J. F.	Design, Fabrication and Testing of an Advanced Composite AH-1[illegible] Tail Section (Tail-Boom/Vertical Fin)	Hughes Helicopters Culver City, CA	USAAMRDL-TR-[illegible] DAAJ02-[illegible]	**Eustis Directorate U.S. Army Air Mobility R & D Laboratories Ft. Eustis, VA**	November [illegible]	AD34[illegible]57	[illegible]
[illegible]	Hoffstedt, D. J. Swatton, S.	Advanced Helicopter Structural Design Investigation	Boeing Vertol Company Philadelphia, PA	USAAMRDL-TR-75-56	Eustis Directorate U.S. Army Air Mobility R & D Laboratory Ft. Eustis, VA	March [illegible]	AD2[illegible]662	[illegible]
[illegible]	Cronkhite, J. Haas, T. J. Winter, R. Cairo, P. Singley, G. T. III	Investigation of the Crash Impact Characteristics of Composite Airframe Structures	Bell Helicopter Textron, Grumman Aerospace Corporation USAAVRADCOM	Technical Paper	American Helicopter Society Washington, D.C.	May [illegible]		[illegible]
[illegible]	Korzun, A.	Investigation of Advanced Helicopter Structural Design, Vol. II - Free Planetary Transmissions Drive	Sikorsky Aircraft Stratford, CT	USAAMRDL-TR-[illegible]B DAAJ02-[illegible]	Eustis Directorate U.S. Army Air Mobility R & D Laboratory Ft. Eustis, VA	May 1976	AD26247	[illegible]
[illegible]	Alesi, A. L. et al.	Review of the Application of Kevlar Fibers To Composite Structures	Army Materials and Mechanics Research Center Watertown, MA	AMMRC-MS-74-[illegible]	U.S. Army Material Command Alexandria, VA	October 197[illegible]	B0008956	[illegible]
67*	**Brown, J. R. Browne, N.**	**Environmental Effects of the Mechanical Properties of High Performance Fibers**	**Materials Research Maribyrnong, Australia**	MRL-R-674	Dept. of Defense **Maribyrnong,** Victoria **Australia**	August 1976	A032858	I, A.

* Pertinent to this program.

TABLE 1. Concluded

ITEM NO.	AUTHOR	TITLE	PERFORMED BY	REPORT NUMBER (CONTRACT NUMBER)	PERFORMED FOR	DATE	AD NO.	CATEGORY
68*	Maximovich, M. G.	Preparation of Foam Composites	Whittaker Corporation San Diego, CA	NASA CR 137597	NASA Ames Research Center Moffett Field, CA	November 1974		I, A., A[illegible]
69	Zisfein, M. B.	Fundamental Problems of Future Aerospace Structures	Franklin Institute Research Laboratory Philadelphia, PA	AFOSR-67-2175	AF Office of Scientific Research Arlington, VA	December 1967	82[illegible],77[illegible]	I
70*	Recht, R. F. Howell, W. G.	Reduction of Hazard From Secondary Fragments Created By Ballistic Penetration of Aircraft	Denver Research Institute University of Denver Denver, CO	USAAVLABS-TR-67-49 (DA 44-177-AMC-399)	U.S. Army Aviation Material Laboratories Ft. Eustis, VA	October 1967	[illegible]5-45[illegible]	F, A.
71	Cully, D. [illegible] et al.	Development of Ballistic Damage Tolerant Flight Control Components Molded of a Short-Fiber Reinforced Composite Material	Goodyear Aerospace Corporation	USAAMRDL TR-72-2[illegible]	Eustis Directorate U.S. Army Air Mobility R & D Lab. Ft. Eustis, VA	September 1972	752918	F, F
72*	Custard, G. H. Donohue, J. D.	Aircraft Fuel Cell Explosion Suppression Systems and Their Applicability to Army Aircraft	Falcon Research & Development Co. Denver, CO	USAAVLABS-TR-67-39 (DA-44-177-AMC-415[illegible])	U.S. Army Aviation Material Laboratories Ft. Eustis, VA	July 1967	824028	F, F

TABLE 2. SUMMARY OF ENCLOSURE FIRE MODELS

SOURCE	PROGRAM NAME	TYPE	OPERA-TIONAL	PREDICTED QUANTITIES
Dayton R.I.	DACFIR	Zone	Yes	Temperatures, Smoke, Toxic Gases, and Fluxes
Harvard	Computer Fire Code IV	Zone	Yes	Temperatures, Smoke, Toxic Gases, and Fluxes
Ohio State	Compartment Fire Code	Zone	Yes	Temperature and Fluxes
NBS	-----	Zone	Yes	Temperature, Smoke, Toxic Gases, and Fluxes
IITRI	RFIRES	Zone	Yes	Temperature, Smoke, and Fluxes
Notre Dame	UNDSAFE II	Field	Yes	Temperatures, Pressure, and Fluxes
JPL	Enclosure Fire-Dynamics Model	Field	No	-----

data and generating new data. These computer codes are termed zone models because they examine a complex fire as a series of simple components (zones) of the fire (e.g., flame, plume, circulation zone, hot ceiling layer, etc.) that are combined by satisfying continuity conditions at the interfaces of the different zones.

The Notre Dame and JPL models use field equations, such as conservation equations for turbulent flow, boundary conditions, initial conditions, etc., to describe the physics and chemistry of the fire. However, these models are very limited in that the Notre Dame Code is only two-dimensional and the JPL program is not yet operational.

Table 2 presents the predictive capability of each of these programs, which are continuously being updated. However, presently the programs are only capable of making qualitative predictions; for instance, comparing different materials or fire scenarios.

In addition, each program emphasizes a particular aspect of the fire from initiation to flashover (e.g., when the bulk of the enclosure volume becomes involved in flames); but none of them is general enough to describe the complete history of the fire. Also, none of them performs any structural degradation analysis. The latter would require a thermal response analysis, to obtain temperature gradients, followed by residual strength and/or stability analyses. Among the computer programs mentioned in the proposal, AVCO's 2500 program appears to be most adequate to perform the thermal response analysis. It accepts all types of surface heating and simultaneously calculates the recession and internal heat transfer. Unlike the APPLE, TRAP 2, CINDA, and AVCO's 5000 programs, the 2500 code is the only one that performs a fairly in-depth chemical decomposition analysis.

The final structural degradation can then be determined by performing strength and stability analyses of the structure under study before and after being damaged, and comparing the results to establish the residual structural properties. It is very important to establish the amount of damage done to the structure in order to make a reliable estimate of residual characteristics.

Survey Results

The logic used to make the computerized search of the NTIS and the various other data bases has been explained in detail in the previous sections. The abstracts of the reports retrieved were reviewed for information relative to the use of composite materials in a helicopter structure subjected to an environment

of fire or explosions. The computer programs and analytical techniques were studied to determine their applicability to an airborne fire or postcrash fire confined to a helicopter-type enclosure. As is evident from the limited number of reports identified in the Literature Survey Section, there has been relatively little reported research concerned with flammability, toxicity, and smoke generation with respect to advanced composite materials that is applicable to primary-type structure such as graphite/epoxy, kevlar/epoxy, or fiberglass/epoxy. The searches of the DDC, DIALOG and ORBIT data bases produced the same results, and at times the reference was available from more than one source.

After the initial assessment, which evaluated in excess of 754 documents of the related subject material, only 72 documents were considered for a more quantitative review. Of these reports and documents only 45 have been considered as pertinent to this program and of interest to continued work in Tasks II and III. The 72 documents quantitatively reviewed are listed in Table 1.

ORGANIZATION SURVEY

The organization survey consisted of a combination of visits and contacts made by Grumman personnel to Government, industry, and academic organizations. The details of each visit and contact made are discussed below. In general, this survey proved to be very informative. The individuals involved were very cooperative; they supplied an extensive amount of information and reports that contributed valuable information to the present study. A large amount of these data has been developed very recently and is not yet available in the computerized library data base in Grumman's Technical Information Center. The reports relevant to the structural degradation and personnel hazards areas are included as part of the literature survey.

Organization Visits

As previously mentioned, visits were made to several Government, industry, and academic facilities. In chronological order they were:

DuPont Seminar. Stamford, Connecticut, 18 May, 1979. The seminar on "Designing With and Using Kevlar In Aircraft" presented information concerning the flammability, toxicity, and smoke generation of Kevlar composite structures.

U.S. Army Material and Mechanics Research Center(AMMRC). AMMRC, Watertown, Massachusetts, was visited by Grumman and Bell Helicopter Textron personnel on 28 August, 1979. The

AMMRC personnel visited were:

Dr. Priest - Asst. Chief of AMMRC - Nonmetallics Dept.
Dom Macaione - Research Chemist - Organic Material Lab.
Bob Sacher - Research Scientist
Al Deone - Research Scientist
Ed Lenoe - Chief - Mechanics of Material Division
Don Oplinger - Team Leader - Mechanics of Advanced Materials
Kanu Gandhi - Engineer - Mechanics of Advanced Materials

The meeting was divided into two sessions with the morning session dealing with the chemistry portion of the program and the afternoon sessions with the structural aspects of the program. During the morning session, the AMMRC personnel, led by Mr. Macaione, reviewed the work accomplished in toxicity and ignition of advanced composite materials. The materials studied were various neat resins, foams, and advanced composite materials such as fiberglass/epoxy, graphite/epoxy and thermoplastics. These studies were performed on materials fabricated by both aerospace manufacturers and AMMRC, and then subjected to isothermal thermogravimetric analysis. The ultimate goal of the AMMRC team is to establish testing techniques as well as U.S. Army standards and procedures. At the conclusion of the morning session, it was agreed that further communication between Grumman and AMMRC would be arranged. Also, because AMMRC has no present smoke evaluation program, they recommended a call to Mr. Tewarson of Factory Mutual Research in Norwood, Massachusetts, as a possible source of related information. Some of the AMMRC test data was reviewed and evaluated for possible usage during the Task II test program.

The afternoon session was a review of the present structural programs at AMMRC and a tour through the test area. However, none of the discussed programs were directly related to the particular program of structural degradation caused by fire.

Ames Research Center (ARC). ARC at Moffett Field, California, was visited by two Grumman personnel on 27 September, 1979. The Ames Chemical Research Projects Office personnel visited were:

Dr. John Parker - Chief - Chemical Research Project Office
Demetrius Kourtides - Head of Materials Group
Richard Fish - Head of Research Testing and Material Laboratories
Joe Mansfield - Research Scientist - Computer Modeling of Open Fires
William Gilwee - Research Scientist
Dr. Domenick Cagliostro - Research Scientist

Also present at this meeting was Dr. Ralph Ballard, a specialist in toxicology and physiology at San Jose State University.

The meeting was headed by Mr. Fish, who described all the work that Ames has accomplished in toxicity, flammability, and structural degradation both in testing and computer modeling of open fires. Each of the other research scientists presented a more in-depth overview of their particular research projects. Dr. Ballard described the work he is doing at Ames under a Navy-funded contract. He is studying the effect of smoke generated from graphite/epoxy material on living organisms of two species (mice and rats). The toxicology of graphite/epoxy fibers and carbon dust is also being studied.

SRI International. SRI, in Menlo Park, California, was visited by a Grumman representative on 28 September, 1979. The SRI personnel visited were Dr. Gordon Pryor and Mr. Ray Alger of the Physical and Life Sciences Divisions.

SRI works on fire-related problems that consist of investigating enclosed fires on ships and the burning of cities as a result of nuclear attacks. They are also very active in the toxicology area and have developed a system and methodology for assessing the incapacitating and lethal effects of smoke associated with the thermal decomposition of various materials. This facility is discussed in Item 19, Table 1.

National Bureau of Standards (NBS). The NBS, Gaithersburg, Maryland, was visited by a Grumman representative on 18 October, 1979, where a meeting was held on the "Validation of Enclosure Fire Models." The meeting was attended by personnel from all the organizations active in this field. The status of each of the computer programs summarized earlier in this report (with the exception of the Notre Dame University Code) was presented, and the capabilities and/or limitations were highlighted. The consensus was that each program emphasizes a particular aspect of the fire but none of them is general enough to describe the complete physics and chemistry of the spreading of the fire.

In addition, all the operational programs use empirical approaches to the solution of this problem, and as a consequence an extensive amount of test data is required as input to the programs. The test data must be obtained under very similar conditions to those under investigation (i.e., flux levels, ventilation patterns, etc.) and therefore, one should be very careful in using the available test data and generating new data. It was also agreed that there is a need to improve these computer simulations, which are presently only capable of making qualitative predictions (i.e., comparing different materials or fire scenarios). It was suggested that more general field equations (e.g., conservation of energy, momentum)

be used to describe a particular aspect, such as flame, plume, and hot ceiling layer, and be used as submodels of the zone (or empirical) model computer programs. Finally, it was suggested that these computer codes be validated by individuals other than those who are involved in the development of them.

U.S. Army Material and Mechanics Research Center(AMMRC). AMMRC, Watertown, Massachusetts, was visited by two Grumman personnel on 18 October, 1979. The purpose of this meeting was for the preparation of the test program required in Task II. A review of the Grumman testing program as outlined in the proposal was discussed with Mr. D. Macaione and Mr. A. Deone of AMMRC, who are both active in the area of flammability and toxicity.

Mr. Deone was helpful in suggesting methods that will expedite the analysis as well as provide good qualitative data. The tour through the laboratories provided an on-site review and comparison of the Grumman and AMMRC test equipment.

Factory Mutual Research. This facility in Norwood, Massachusetts, was visited by Grumman personnel on October 19, 1979, as recommended in the 28 August, 1979, meeting at AMMRC. Mr. A. Tewarson of Factory Mutual reviewed his work in flammability relating to large industrial factories. The objective of his work was to develop simple technologies to evaluate the flammability parameters of polymeric materials using a laboratory-scale flammability apparatus, which was developed by Mr. Tewarson. Another object was to obtain data useful as input parameters for fire modeling and for making engineering decisions as to the safe applications of the polymers for various end users.

Organizations Contacted

As a continuation of the organization survey, the following organizations were contacted; the personnel and their respective areas of interest are summarized below.

Boeing Company, Seattle, Washington. Mr. Gerald Johnson. Area: Data bank of fire properties of materials used in commercial aircraft and full-scale testing of the 707 fuselage.

Dayton Research Institute, Dayton, Ohio. Dr. Charles D. MacArthur. Area: Computer Program Dayton Aircraft Fire Model (DACFIR) for aircraft cabin fires.

Department of Transportation, Washington, D.C.. Mr. Chuck McGuire. Area: Coordinator of all programs on fire-related problems in transportation.

FAA Civil Aeromedical Institute, Oklahoma City, Oklahoma. Dr. Crane, Mr. Chandler, Dr. Kirkham. Area: Working in flammability and toxicity studies related to fiberglass and Kevlar/epoxy used on the Boeing 747. In addition, they are beginning to generate standard test procedures for nonmetallic interior structure.

FAA - National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey. Mr. G. Sarkos. Area: Evaluating flammability, toxicity, and smoke generation on fiberglass/epoxy sandwich panels for cabin interior structure.

Harvard University, Cambridge, Massachusetts. Prof. Howard W. Emmons. Area: Computer program Fire Code IV for room fires.

Illinois Institute of Technology Research Institute, Chicago, Illinois. Dr. Ronald Pape. Area: Computer program RFIRES for room fires.

Jet Propulsion Laboratory, Pasadena, California. Mr. Perry Bankston. Area: Aviation Safety; has begun to develop a computer program for enclosure fires.

National Bureau of Standards, Gaithersburg, Maryland. Dr. Merritt M. Birky, Dr. Bernie McCaffrey, Dr. Robert Levine. Area: Computer program for room fires, scale model testing, flammability, toxicity, and smoke generation problems related to building and room fires.

NASA-Lewis Research Center, Cleveland, Ohio. Mr. Harold Smith, Mr. Kevin Bowles. Area: Release of graphite fibers from burning of graphite/epoxy structures and their effects on electrical equipment.

Ohio State University, Columbus, Ohio. Prof. Edwin Smith. Area: Computer Program Compartment Fire Model and O.S.U. Combustion Analyzer Apparatus for generating fire properties of materials.

Transportation Systems Center, Cambridge, Massachusetts. Mr. William Hataway. Area: Vulnerability of graphite/epoxy in automotive industry and general safety for the Department of Transportation.

University of Notre Dame, South Bend, Indiana. Prof. K. T. Yang. Area: Computer program UNDSAFE II for room fires.

Naval Weapons Center, China Lake, California. Mr. Conrad Driussi. Area: Thermal damage and fire extinguishment of self-sustaining carrier deck fires, and fiber release of graphite/epoxy in open pit fires.

3. TEST AND EVALUATION

Task II consisted of preparation and submittal of a test plan, followed by conducting the various tests in accordance with that plan. Three types of tests were conducted: ballistics tests, smoke and toxicity tests, and structural degradation tests. Those tests and the results are discussed below.

BALLISTICS TESTS

Background

Ballistics tests were conducted at the ATL Ballistic Test Range. The intent of the tests was to determine whether or not an HEI impact would initiate burning of the composite material. The tests were conducted on 13 June, 1980, and witnessed by Mr. W. T. Alexander, ATL Technical Representative.

Test Setups

The typical test setup is illustrated in Figure 2.

Test Apparatus

5Tl Programmable Control System (Texas Instruments)
Hewlett Packard Measuring System, Mdl 5300A
Electronic Ballistic Velocity Screens
Video Monitoring System:
- JVC Color TV Camera
- JVC Color Portable Video Tape Recorder
- JVC Color TV Monitor

Photo Equipment:
- Photosonics Camera (2)
- Arriflex Camera (1)
- 35mm Camera (1)
- Speed Graphic (1)

Mounting Ring
Weapon:
- HEI Mann Barrel with Frankford Rest
- HEI Safety Breech with Electric Firing Mechanism

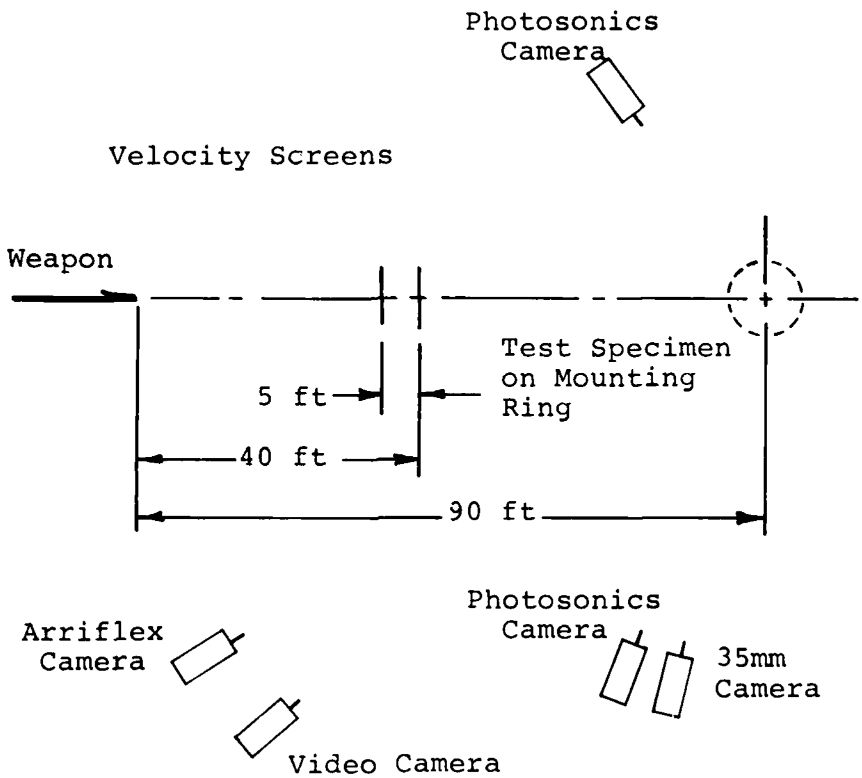


Figure 2. Typical test setup.

Test Specimens

The ballistic test specimens were described in the test plan. Portions of that description are included in the following discussions for clarity.

Composite Door. The sheet-stiffened, built-up door was made from a Kevlar 49/epoxy fabric impregnated with a 250°F curing resin system (Hexcel 185). The door used integrally formed, hat-shaped members for stiffening. Figures 3 and 4 are photographs of this specimen.

Fuselage/Shell Structure. The honeycomb sandwich fuselage structure consisted of 350°F curing graphite/epoxy skins bonded to Nomex honeycomb core. This structure was half-size, and consisted of half of the fuselage section. The other half-section was made of a Kevlar/epoxy laminate. The section was provided with a floor made from Kevlar/epoxy skins bonded to a Nomex core. This sandwich structure floor was bonded to a crash-attenuating substructure of alternate rows of Nomex core and aluminum core. The ends were closed with plywood to provide both rigidity and a closed volume for the ballistics tests. The window apertures remained open. Photographs of this test specimen are presented in Figures 5, 6 and 7.

Test Procedures

Composite Door. The door specimen was secured to a mounting ring as shown in Figures 8 and 9. The ring was then rotated to provide a 30-degree impact angle in accordance with the test plan. An aluminum function plate, 2024-T3, 0.040-inch thick, was positioned in front of the specimen to provide a 5.5-inch standoff to simulate a superquick fuse. The specimen was then impacted with two HEI projectiles.

Fuselage/Shell Structure. The fuselage/shell structure was also secured to the mounting ring as shown in Figure 10. The ring was then rotated to provide a 45-degree impact angle in accordance with the test plan. An aluminum function plate, 2024-T3, 0.040-inch thick, was positioned in front of the specimen to provide a 5.5-inch standoff to simulate a superquick fuse. The specimen was then impacted with two HEI projectiles.

Test Results

Composite Door. In Test 1, the HEI projectile impacted the function plate and detonated on the face skin of the door specimen. Structural members of the door were severed and the plexiglass window shattered, as may be seen in the photographs presented in Figures 11 and 12. The velocity screens malfunctioned; therefore, the actual velocity was not available. The

Figure 3. Composite door specimen - exterior view.

Figure 4. Composite door specimen - interior view.

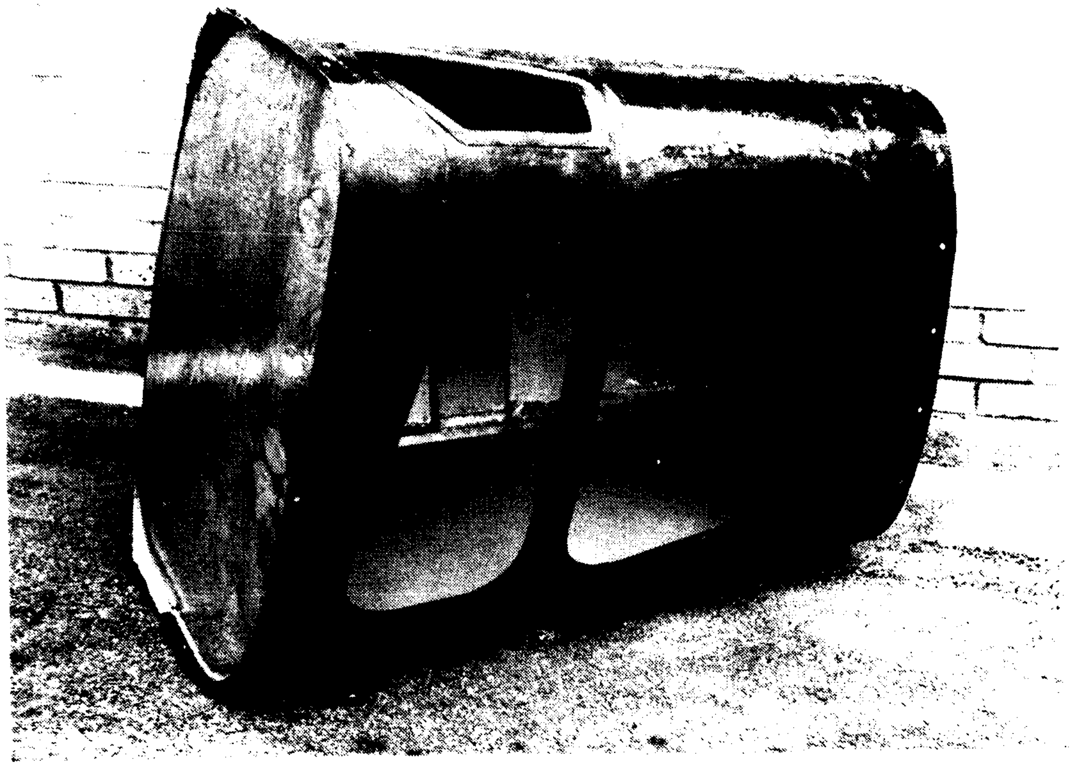


Figure 5. Shell structure specimen - view of graphite/epoxy test side.

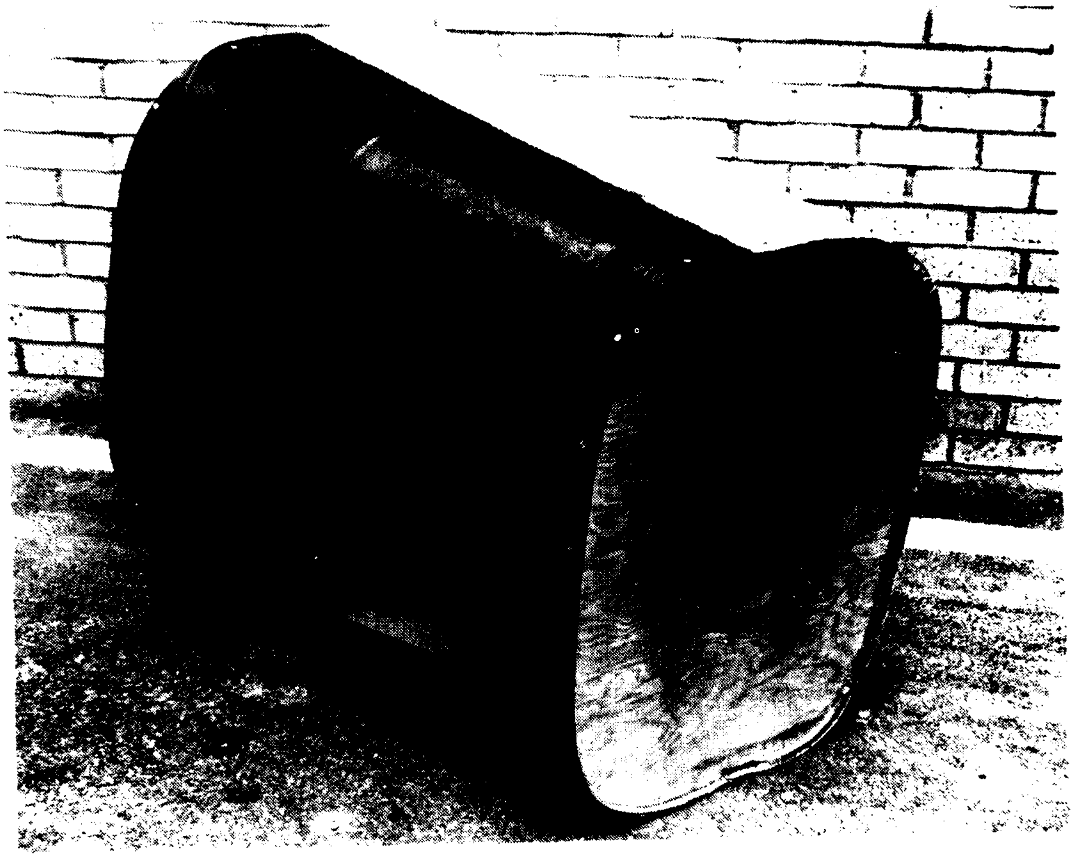


Figure 6. Shell structure specimen - view of test side showing bonded-in floor.

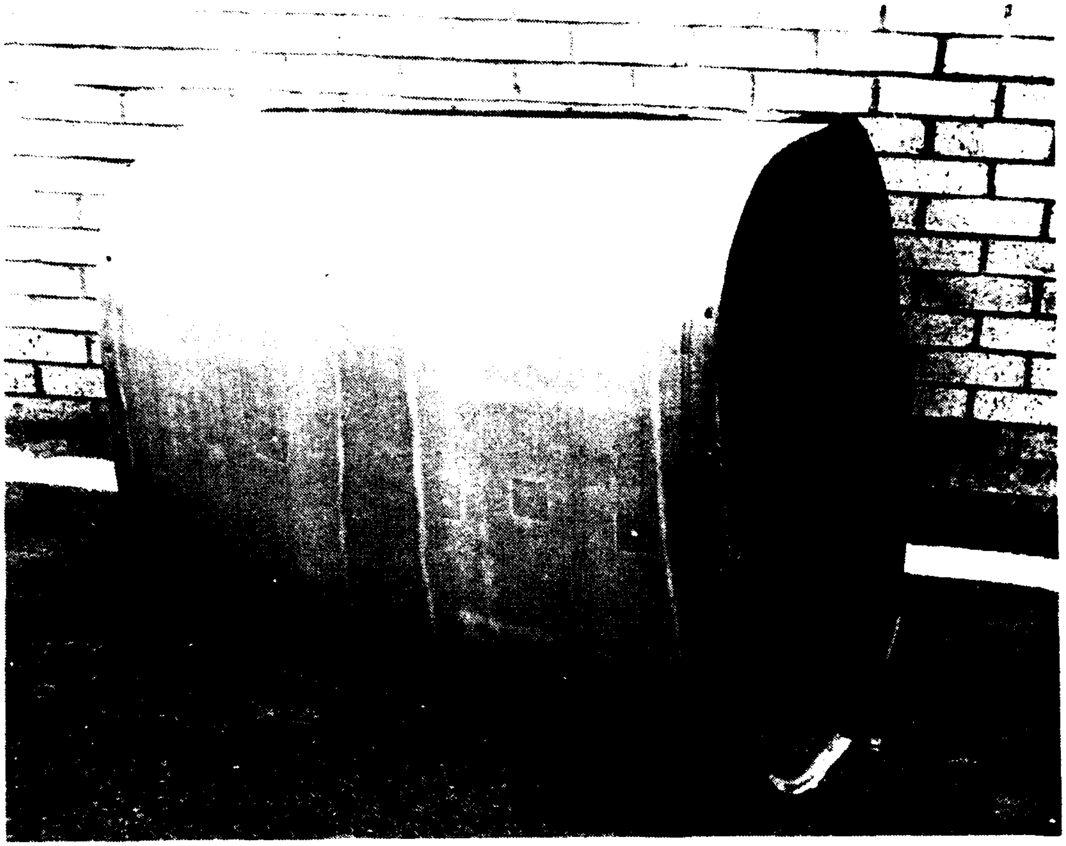


Figure 7. Shell structure specimen - view of Kevlar/epoxy skin provided for closure.

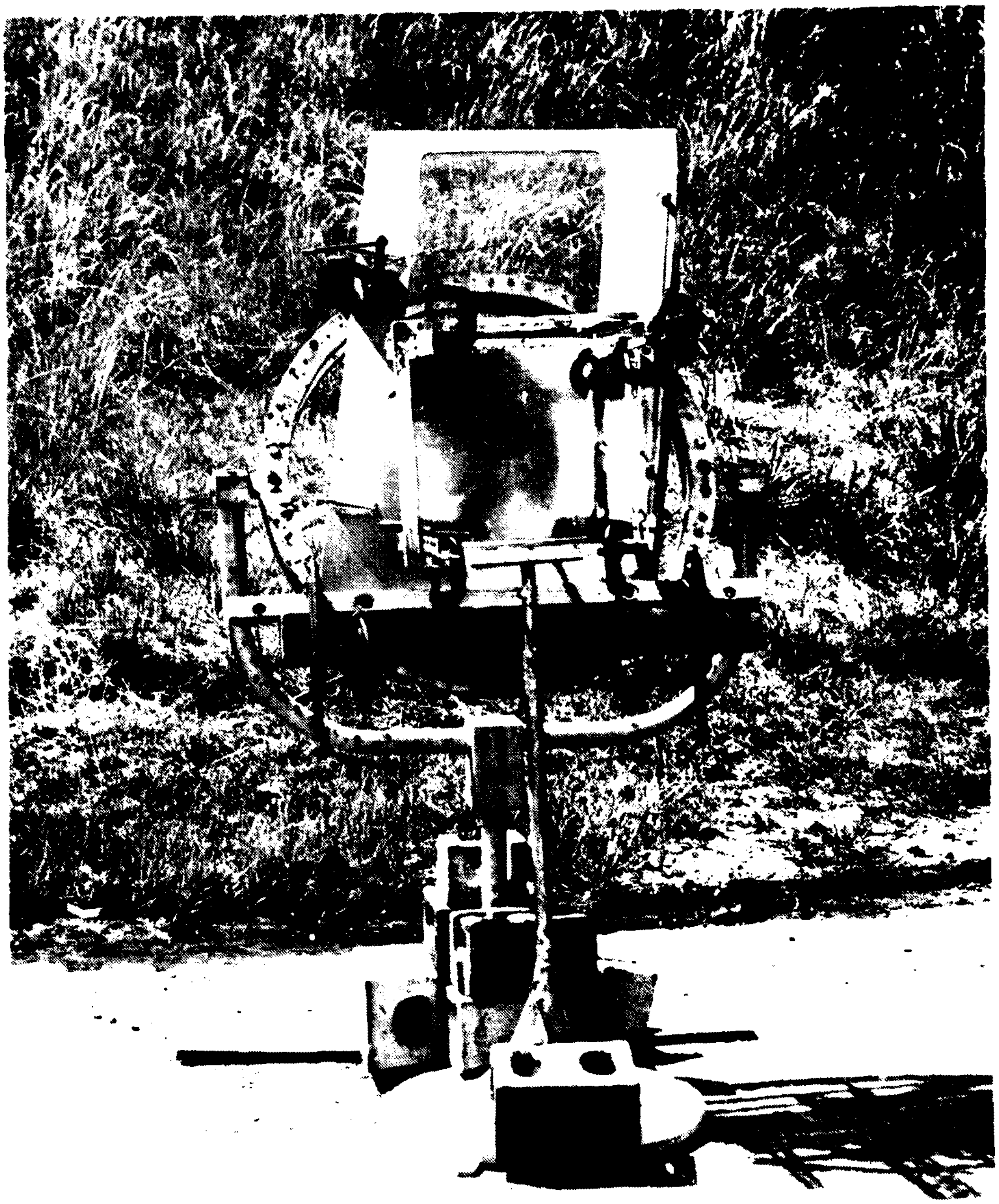


Figure 8. Composite door - entrance side before impact.

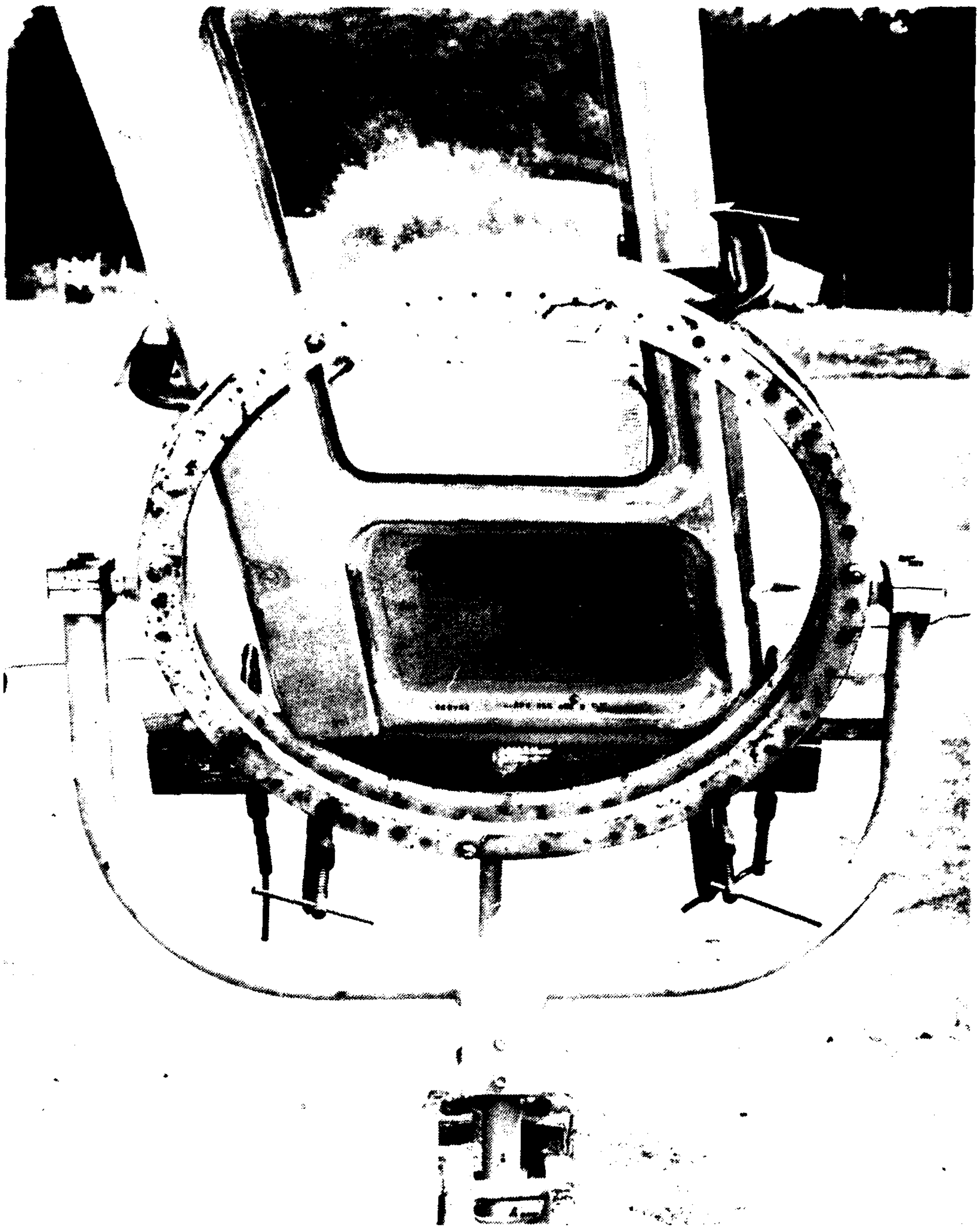


Figure 9. Composite door - exit side before impact.

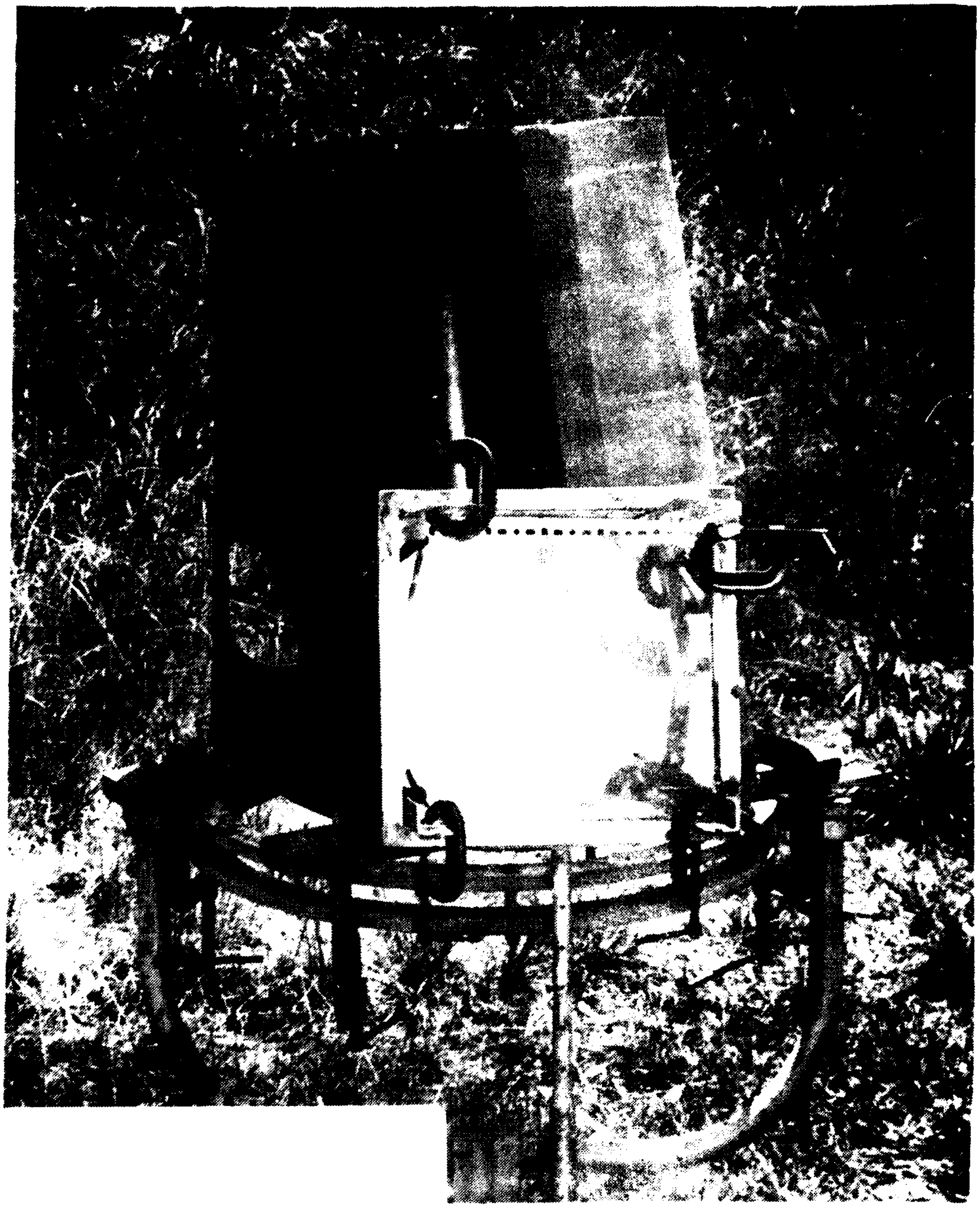


Figure 10. Shell structure - entrance side prior to impact.

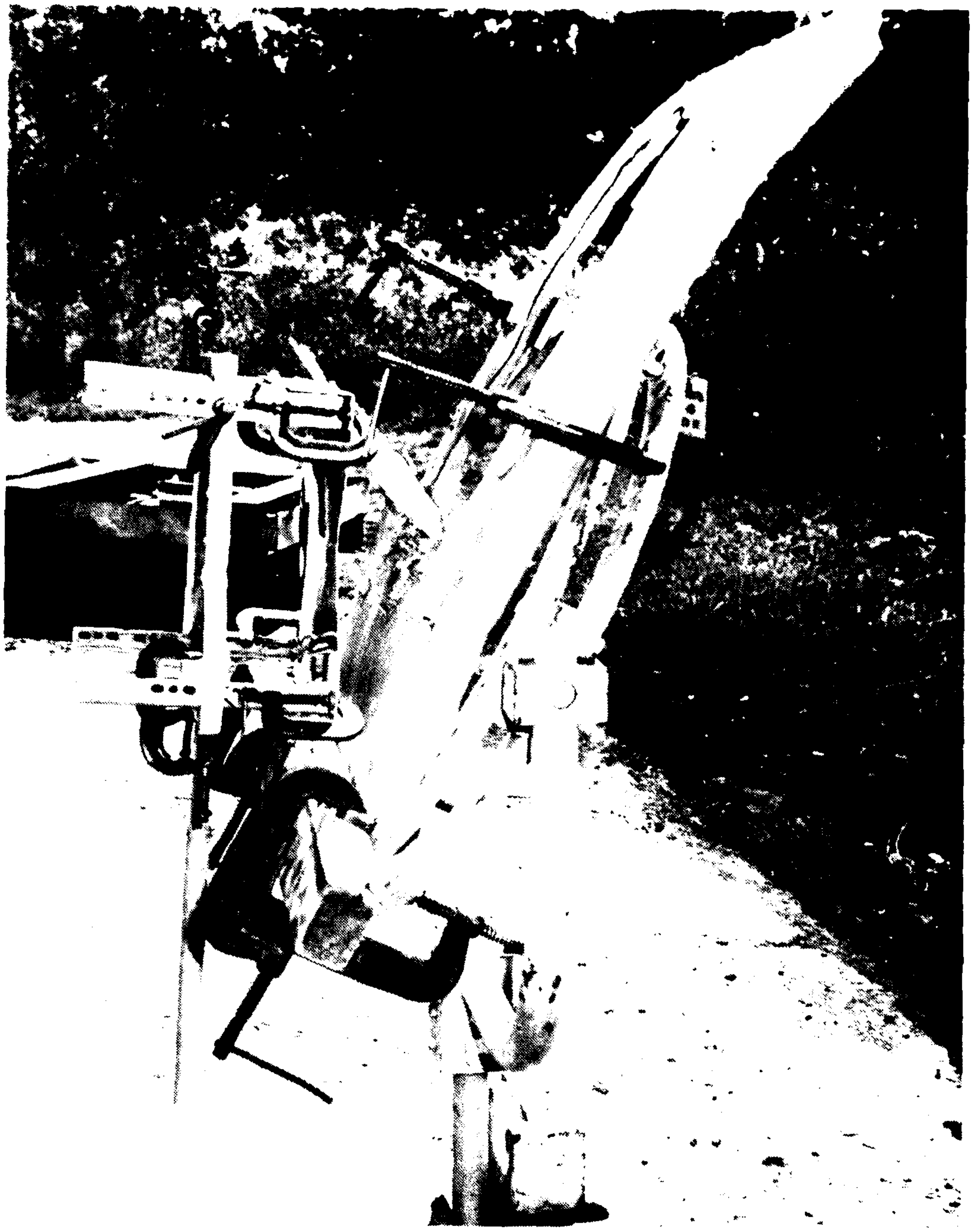


Figure 11. Composite door after Test 1 - entrance side.

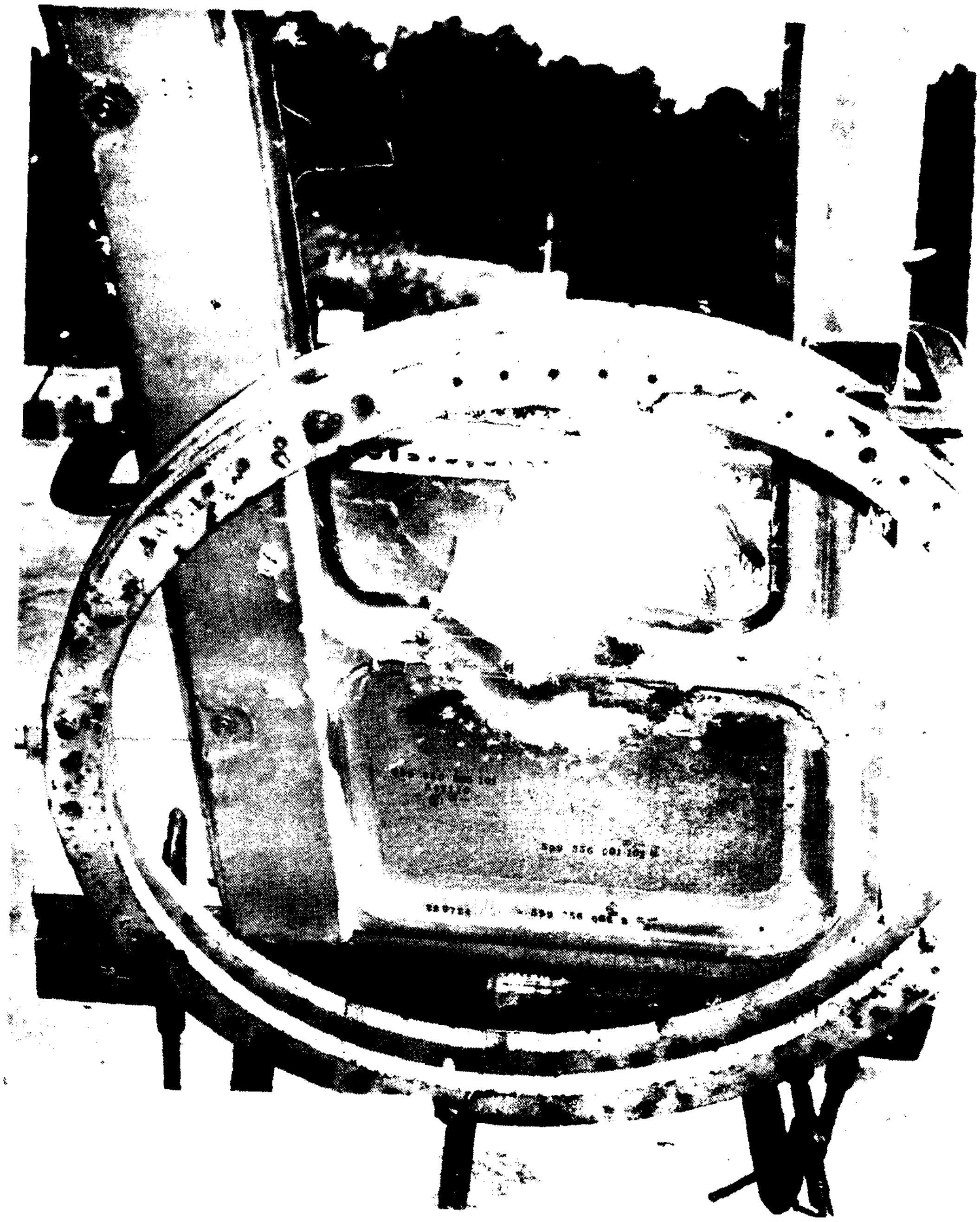


Figure 12. Composite door after Test 1 - exit side.

round was downloaded to approximately 2000 feet per second. No ignition or burn of the test article was observed.

For Test 2, the door was repositioned and secured to the mounting ring. Mr. Alexander requested that the impact point be located in the lower right-hand corner of door as indicated in Figure 13. The HEI projectile impacted the function plate and detonated on the face skin of the door specimen. Overpressure resulting from round detonation propagated through the structural members, causing the door to delaminate completely, and to break into several pieces, as may be seen in Figure 14. Again, actual velocity was not measured, but the HEI round was downloaded to approximately 2000 feet per second. No ignition or burn of the test article was observed.

Fuselage/Shell Structure. In Test 3, the HEI projectile impacted the function plate and detonated against the face skin approximately 10 inches from the end plate and 4 inches below the decking in accordance with the test plan. The damage to the structure may be seen in Figures 15 and 16. No ignition or burn of the test article was observed.

For Test 4, the shell structure was repositioned and secured to the mounting ring. Mr. Alexander requested that the impact point be located 11 inches down from the top edge of the end plate and directly on the edge of the decking as indicated in Figure 16. The HEI projectile impacted the function plate and detonated against the face skin of the specimen. The damage extent is shown in Figure 17. The exit side of the test article after Tests 3 and 4 is shown in Figure 18. No ignition or burn of the test article was observed.

Test Article Disposition

The test articles were returned to the ATL Structures Technical Area after testing was completed.

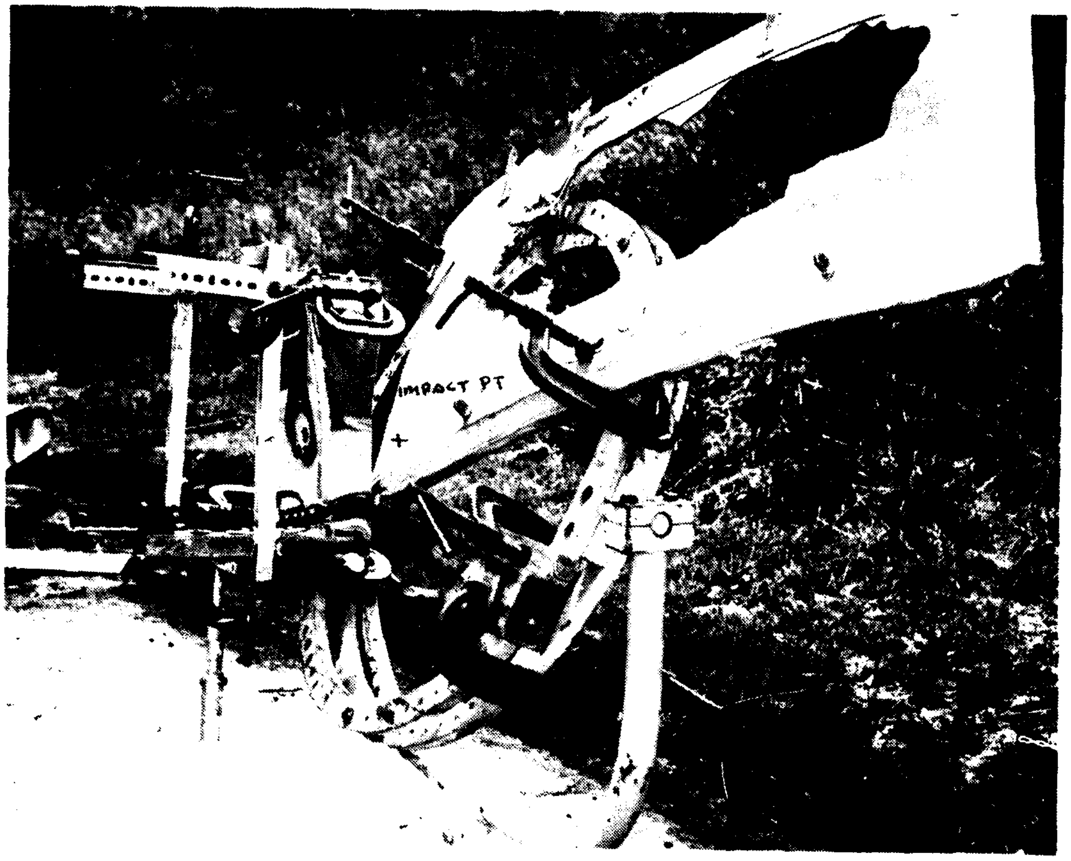


Figure 13. Composite door prior to Test 2 - designated impact point.

Figure 14. Composite door after Test 2.

Figure 15. Shell specimen after Test 3 - entrance side.

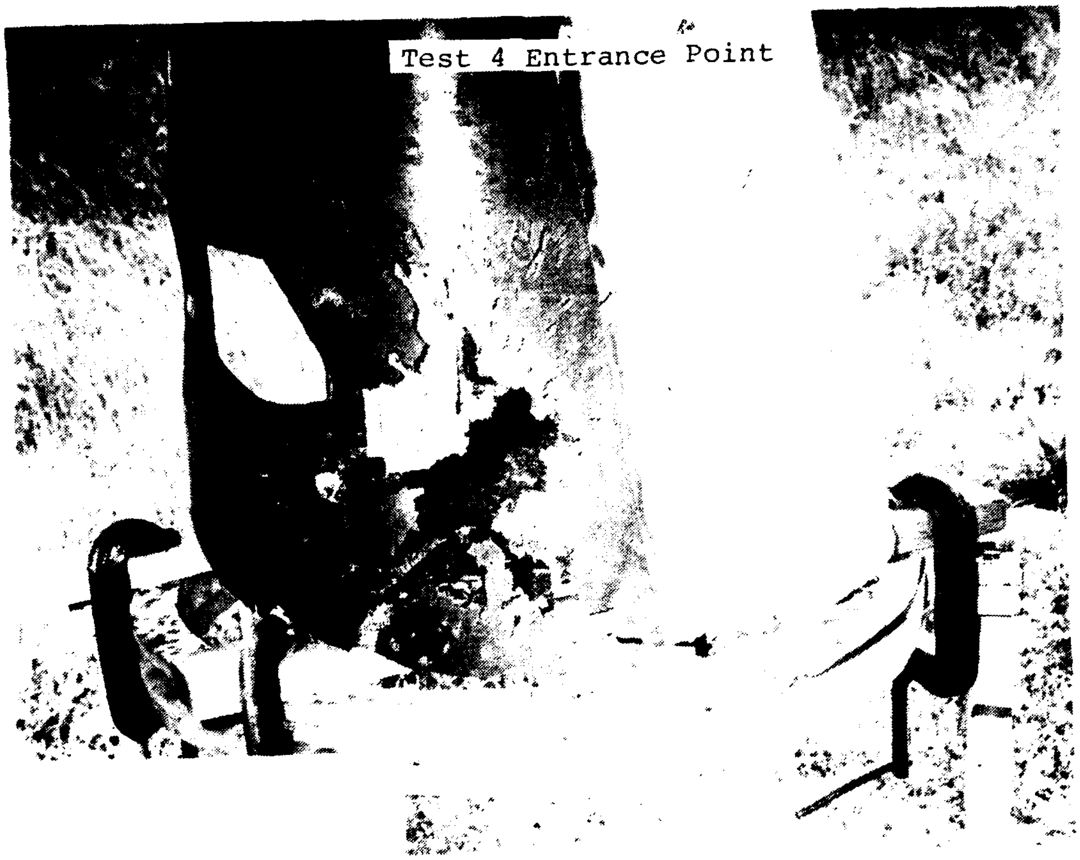


Figure 16. Shell specimen prior to Test 4 - designated entry point.

Figure 17. Shell specimen after Test 4 - entry side.

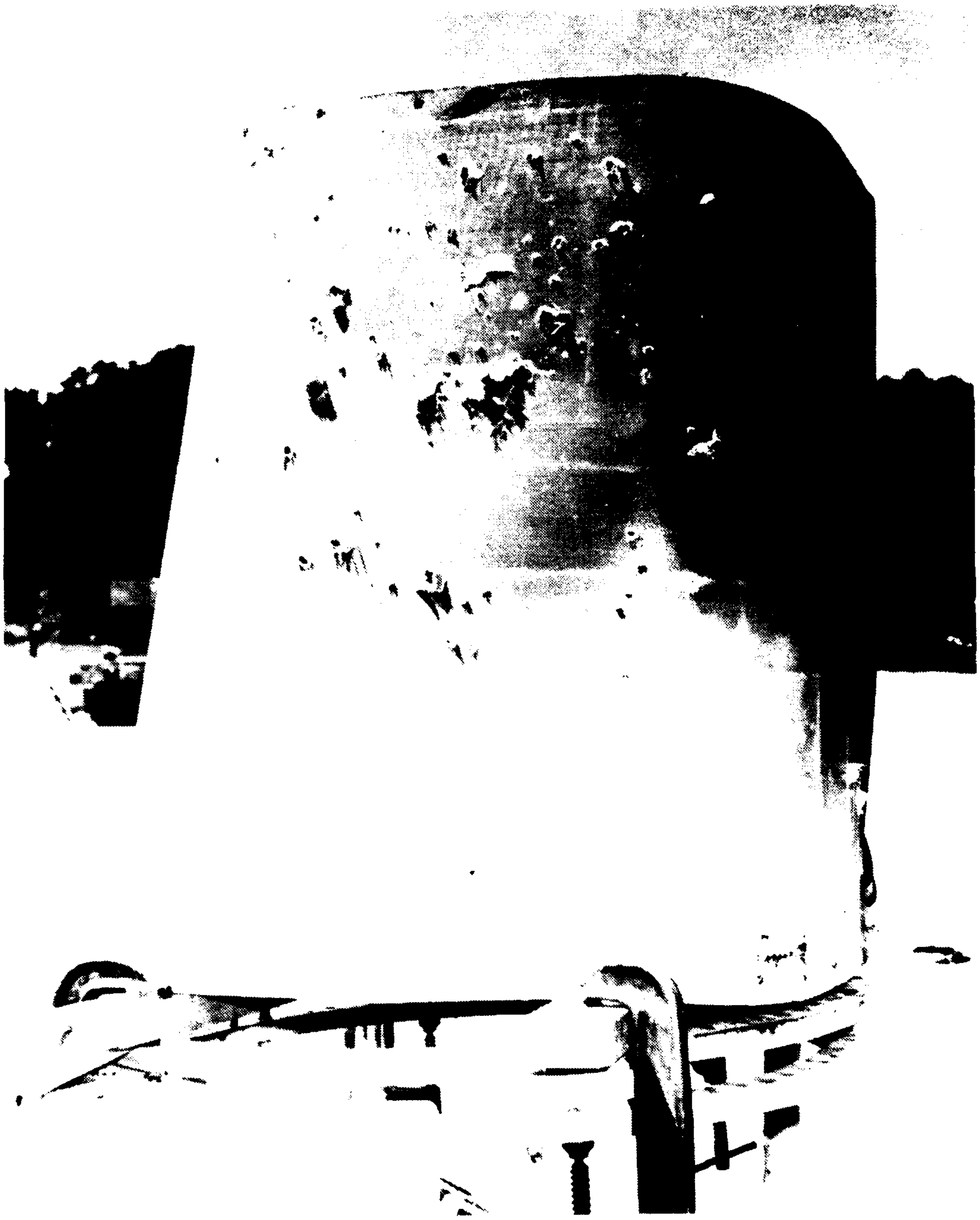


Figure 18. Shell specimen after Test 4 - Kevlar/epoxy exit surface.

SMOKE PRODUCTION TESTS

Purpose of the Tests

The purpose of these tests was to establish means of measuring smoke from burning advanced composite specimens, and to evaluate their effect on personnel with respect to obscured vision and respiratory irritant. These tests were performed in a smoke chamber in accordance with ASTM D2843 on specimens measuring 1 inch x 1 inch.

Description of the Specimens

Test materials were furnished in panels by BHT to GAC as shown in Figure 19. One-inch-square specimens were cut from these panels and tested in the dry and fuel-soaked conditions. Test specimens are shown in Figure 20.

Litter Door Specimens

1. Kevlar/epoxy with and without Tedlar backing.

2. Tedlar backing was removed by grinding from the delivered specimens.

3. Specimens were yellow in appearance.

4. For consistency, all specimen samples were tested with the Tedlar side up, and away from the flame.

Shell Structure. Graphite/epoxy face sheets bonded to an inner Nomex core.

Control Specimens. For comparison, control samples were tested both dry and soaked in JP-4 fuel.

1. One-half-inch plywood.

2. Acrylonitrile-butadiene-styrene (ABS).

Discussion

Test Methods. ASTM procedure D2843-77, "Standard Test Method for Density of Smoke from the Burning or Decomposition of Plastics," was the basic guide for this test. The test apparatus is shown in Figures 21 and 22.

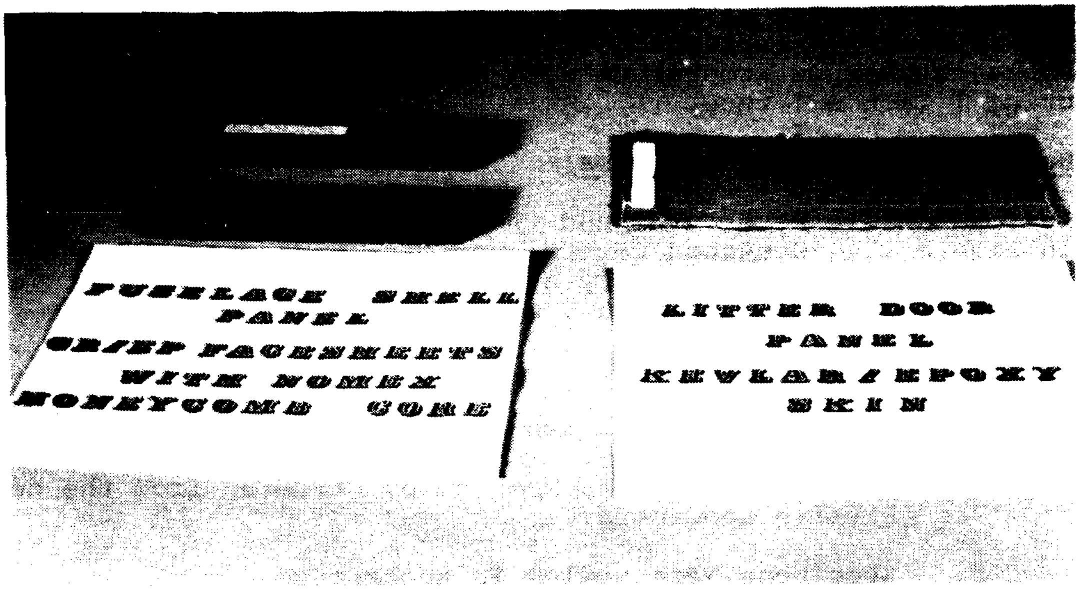


Figure 19. Test panels for smoke and toxicity tests.

Figure 20. Test specimens for smoke testing.

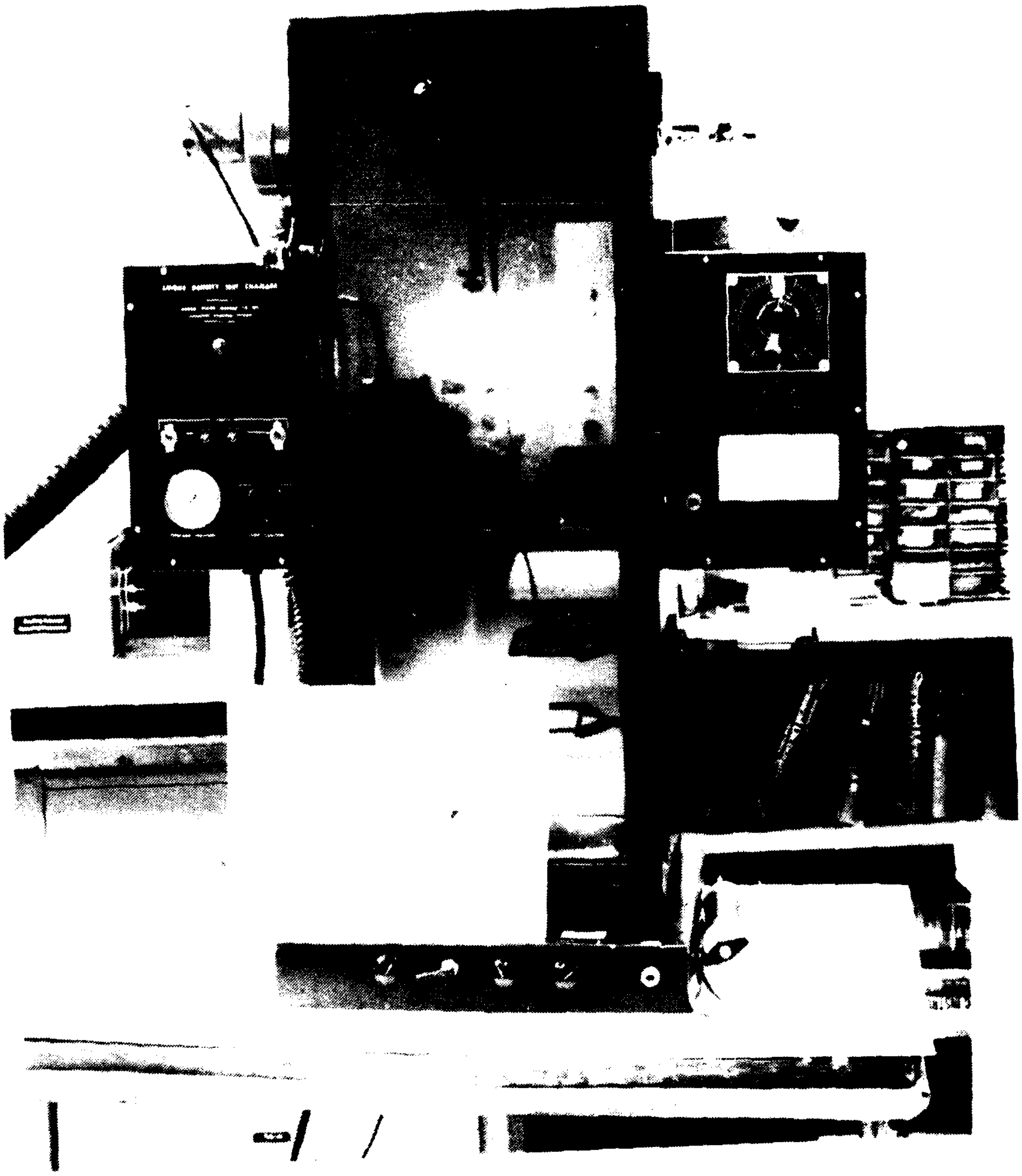


Figure 21. Smoke testing chamber used in ASTM D2843-77.

Figure 22. Exhaust system for the ASTM D2843-77 test chamber.

The specimen was placed into the testing chamber on a supporting metal screen as shown in Figure 23 for a Kevlar/epoxy sample. It was exposed to flame for the duration of the test and the smoke was trapped within the closed chamber. Figures 24 through 27 show the smoke chamber at four successive times during a test. The chamber was equipped with a light source, a photoelectric cell, and a meter to measure light absorption horizontally across the 12-inch light beam path. Samples were tested in duplicate, unless additional runs were warranted because of erratic results. A single test was made on control specimens. The light absorption data for the various fuels at each interval were averaged and plotted versus time. The area under this curve divided by the graph's total area is the smoke density rating in percent. The highest point on the plot measured in percent light absorption is the maximum smoke density.

Test Parameters/Instrumentation

- Specimen Size: 1 inch x 1 inch
- Test Duration: 4 minutes
- Measurement Intervals: 15 seconds
- Fuel Soak Samples: 30-second soak in JP-4 fuel
- United States Testing Company 7700 Smoke Density Chamber
- Ignition Source: Propane Burner - 40 psi pressure
- Keuffel and Esser 4242 Compensating Polar Planimeter

Test Results

The results of the tests are reported in Table 3. The detail specimen test data, discussed below, are the accumulated data obtained while performing each test on the various advanced composite specimens. These data are then plotted, comparing average light absorption against time for each of the test specimens and each test condition.

Litter Door Specimens. The following data are for test samples that were cut into 1-inch x 1-inch specimens from a Kevlar-49/epoxy fabric panel representative of the BHT Model 206L Composite Litter Door. This panel was cut from a litter door by BHT and cut by Grumman in such a manner that produced edges free from projecting fibers, chips or ridges. A Tedlar backing film was on the inside surface of the door section. Tests were conducted with and without this layer.

Figure 23. Kevlar/epoxy specimen placed on holder prior to smoke generation test.

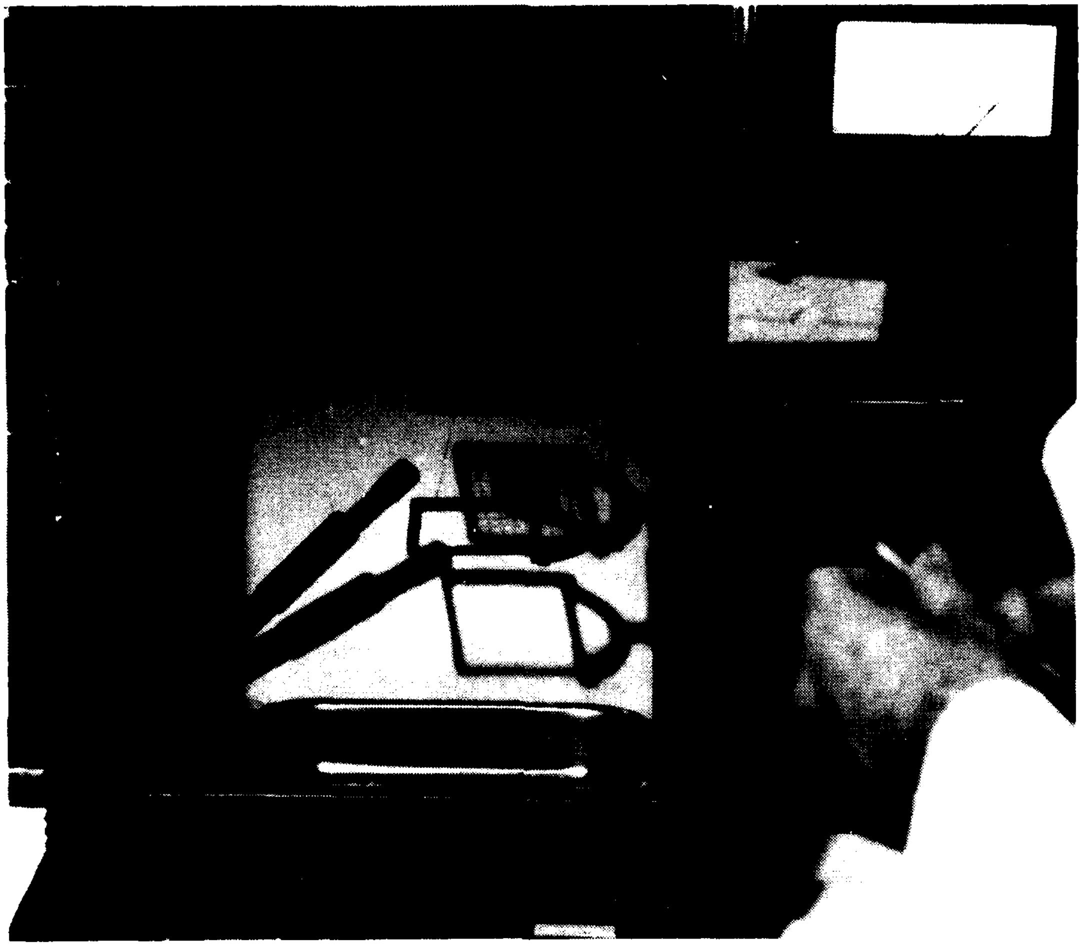


Figure 24. Smoke generation test - start of test (flame applied).

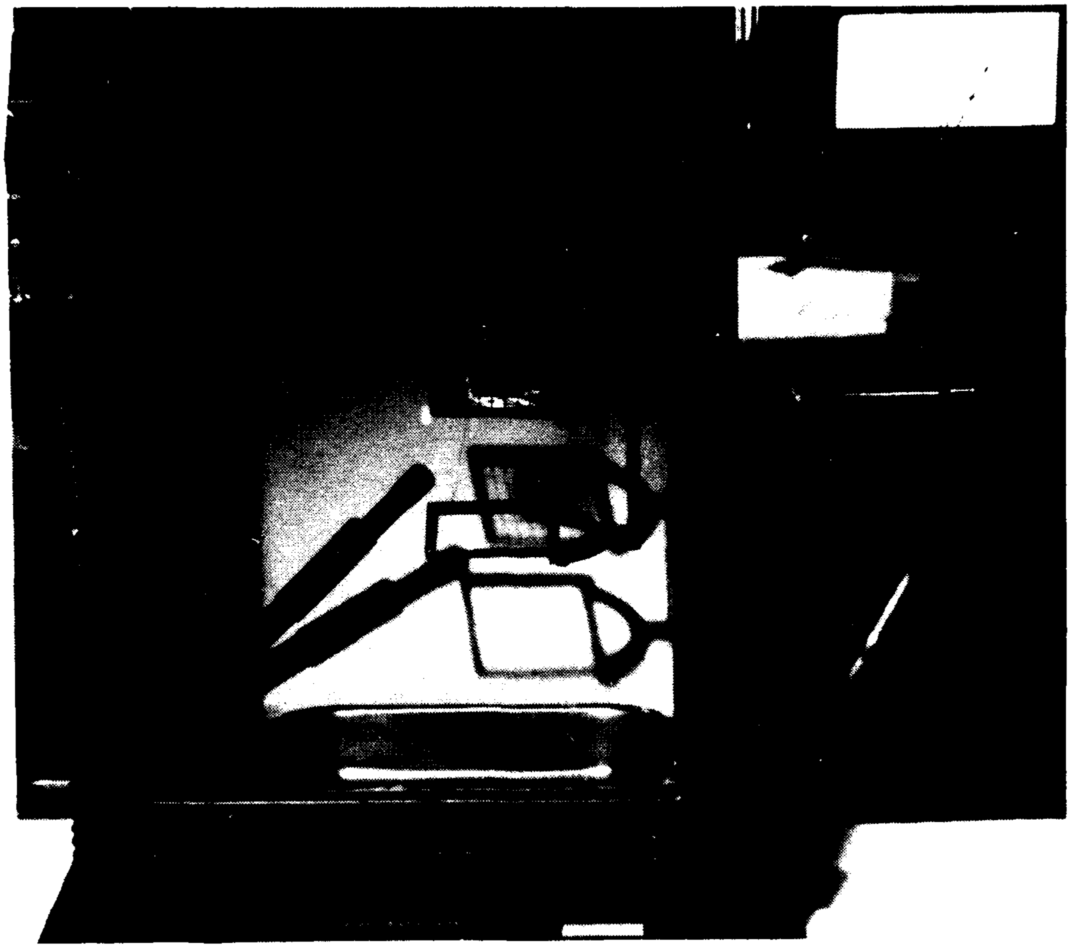


Figure 25. Smoke generation test - initiation of burning.

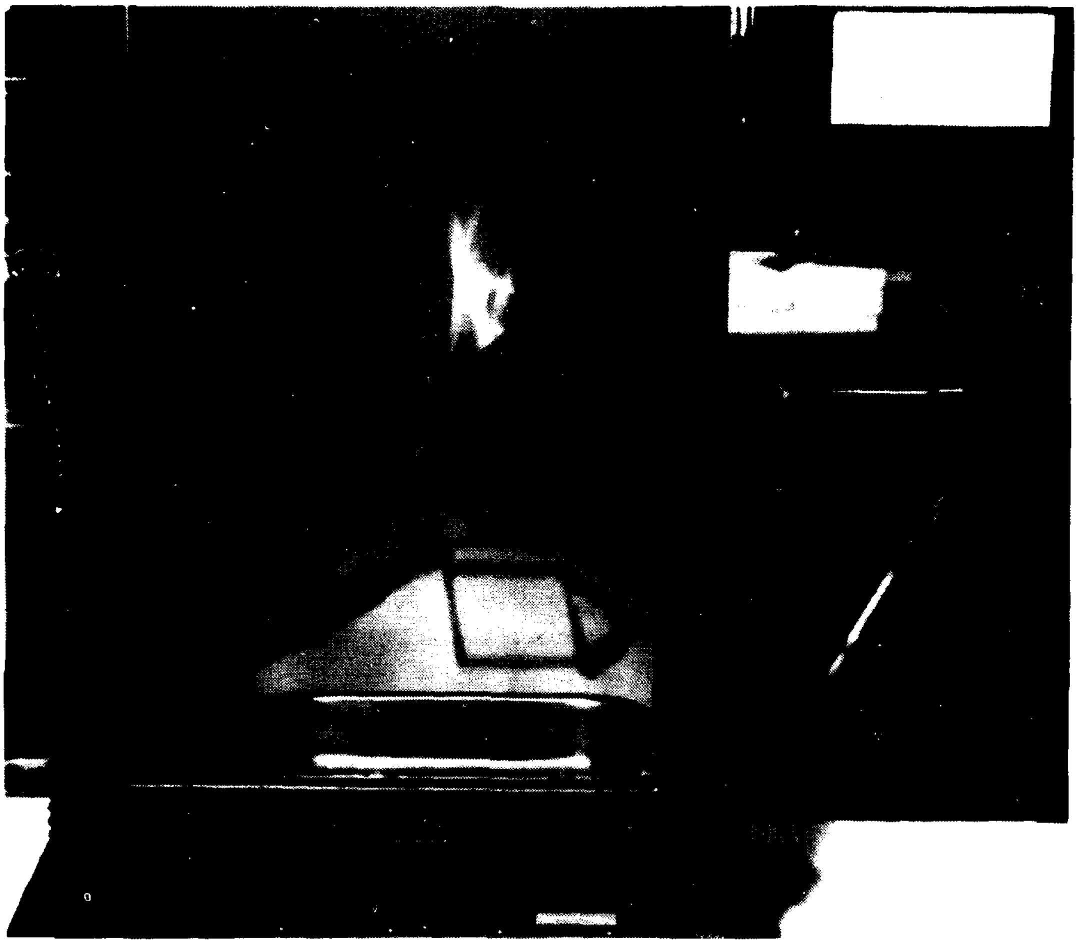


Figure 26. Smoke generation test - vigorous burning.

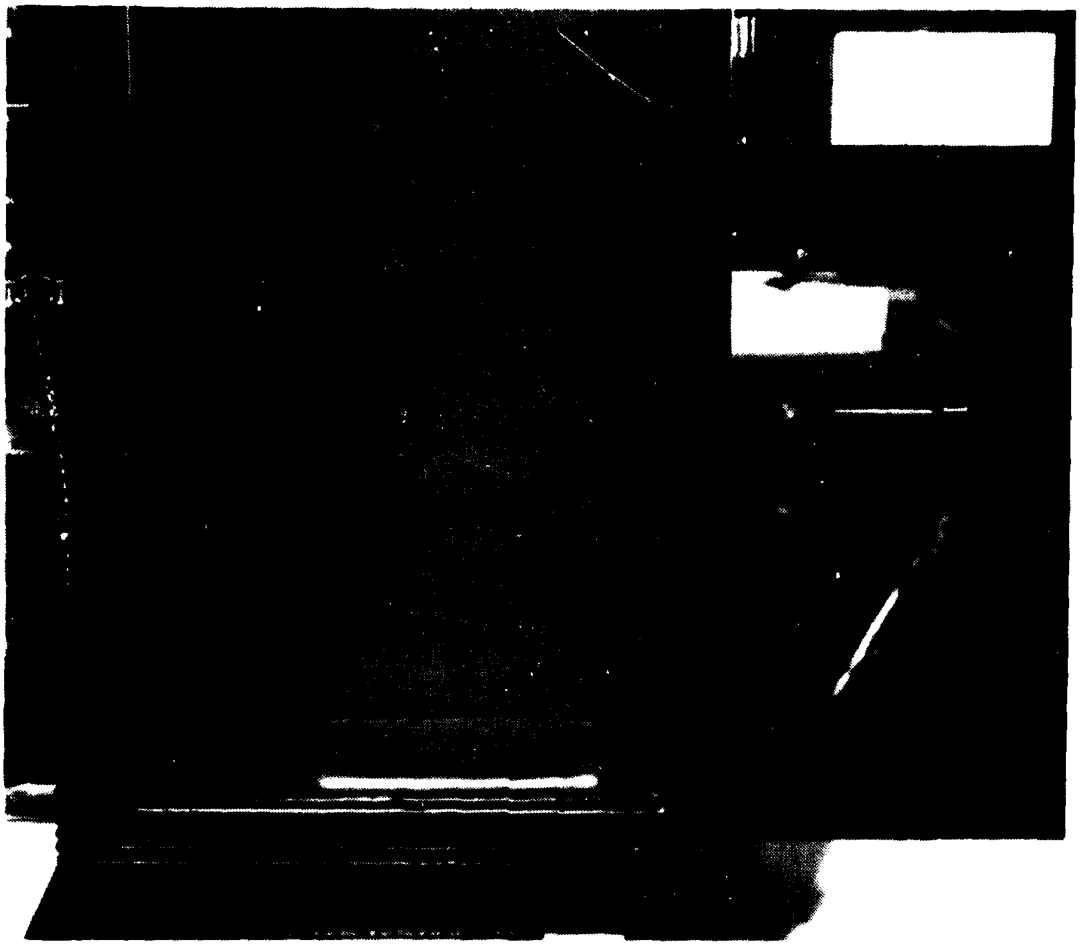


Figure 27. Smoke generation test - char, burning complete (flame still applied).

TABLE 3. DATA SUMMARY - SMOKE TEST

	Number of Trials	Smoke Density Rating(%)	Maximum Smoke Density(%)
Litter Door With Tedlar (Dry)	2	72.5	96.7
Litter Door With Tedlar (Fuel Soaked)	2	79.4	98.1
Litter Door Without Tedlar Film (Dry)	2	73.2	96.1
Litter Door Without Tedlar (Fuel Soaked)	2	70.7	95.6
Shell Structure (Dry)	4	51.8	71
Shell Structure (Fuel Soaked)	3	58.2	82.3
Wood (Dry)	1	0.14	1
Wood (Fuel Soaked)	1	2.1	11
ABS (Dry)	1	92.9	99.9
ABS (Fuel Soaked)	1	91.4	99.8

These samples were tested both dry and after being soaked for 30 seconds in JP-4 fuel. The accumulated data for the Tedlar backed samples is presented in Tables 4 and 5 and in Figures 28 and 29. The data for the samples without Tedlar backing are presented in Tables 6 and 7 and in Figures 30 and 31.

Fuselage Shell Structure. The following data are for test samples that were cut into 1-inch x 1-inch specimens from a honeycomb sandwich construction panel that was representative of a fuselage shell structure. This panel was fabricated by BHT from 3501-6/AS graphite/epoxy facesheets with Nomex core, and cut by Grumman in such a manner that the edges were free from projecting fibers, chips or ridges. These samples were tested both dry and after being soaked for 30 seconds in JP-4 fuel. The accumulated data are shown in Tables 8 and 9 and Figures 32 and 33.

Control Specimens. Control specimens, with known properties, were fabricated. A 1/2-inch-thick plywood sample measuring 1 inch x 1 inch and a plastic ABS material of the same measurement were used for this evaluation. Samples were tested both dry and after a 30-second JP-4 fuel soak. The accumulated data are presented in Tables 10 and 11 and in Figures 34 through 37.

Conclusions

- Individual test results indicated that the Model 206L advanced composite litter door with Tedlar backing is judged to be the highest smoke producer of the helicopter specimens.

- The litter door without the Tedlar backing specimen generally evolved less smoke than the litter door with Tedlar, although the results are somewhat debatable in the dry condition.

- The advanced composite shell structure sample resulted in the lowest smoke production.

- The effect of the 30-second fuel soak was:

    - A pronounced increase in smoke production in the litter door with Tedlar and shell structure samples.

    - A slight decrease in smoke production in the litter door without Tedlar sample.

TABLE 4. LIGHT ABSORPTION VS. TIME TEST DATA (KEVLAR 49/EPOXY WITH TEDLAR BACKING)

TIME (MIN:SEC)	Dry Specimen		Fuel-Soaked Specimen	
	Percent Light Absorption (Avg of 2 Trials)	Standard Deviation of the 2 Trials	Percent Light Absorption (Avg of 2 Trials)	Standard Deviation of the 2 Trials
0	0	0	0	0
0:15	32.5	3.5	56.5	9.2
0:30	96.7	2.1	98.1	0.4
0:45	94.9	1.9	96.3	0.6
1:00	93.1	1.5	94.7	0.4
1:15	38.5	3.8	92.9	0.6
1:30	84	2.8	90.9	0.6
1:45	80	2.8	87	2.8
2:00	77	2.8	83	1.4
2:15	74	2.8	81	1.4
2:30	70.5	2.1	79.5	2.1
2:45	68	2.8	77.5	2.1
3:00	65.5	2.1	76	2.8
3:15	64	1.4	74	2.8
3:30	62.5	0.7	72.5	3.5
3:45	60.5	0.7	71.5	3.5
4:00	59.5	0.7	70.5	3.5

TABLE 5. SUMMARY OF TEST DATA (KEVLAR 49/EPOXY WITH TEDLAR BACKING)

	Dry Specimens	Fuel-Soaked Specimens
Area Under Curve	50.72 in.^{2}	55.60 in.^{2}
Smoke Density Rating	72.5%	79.4%

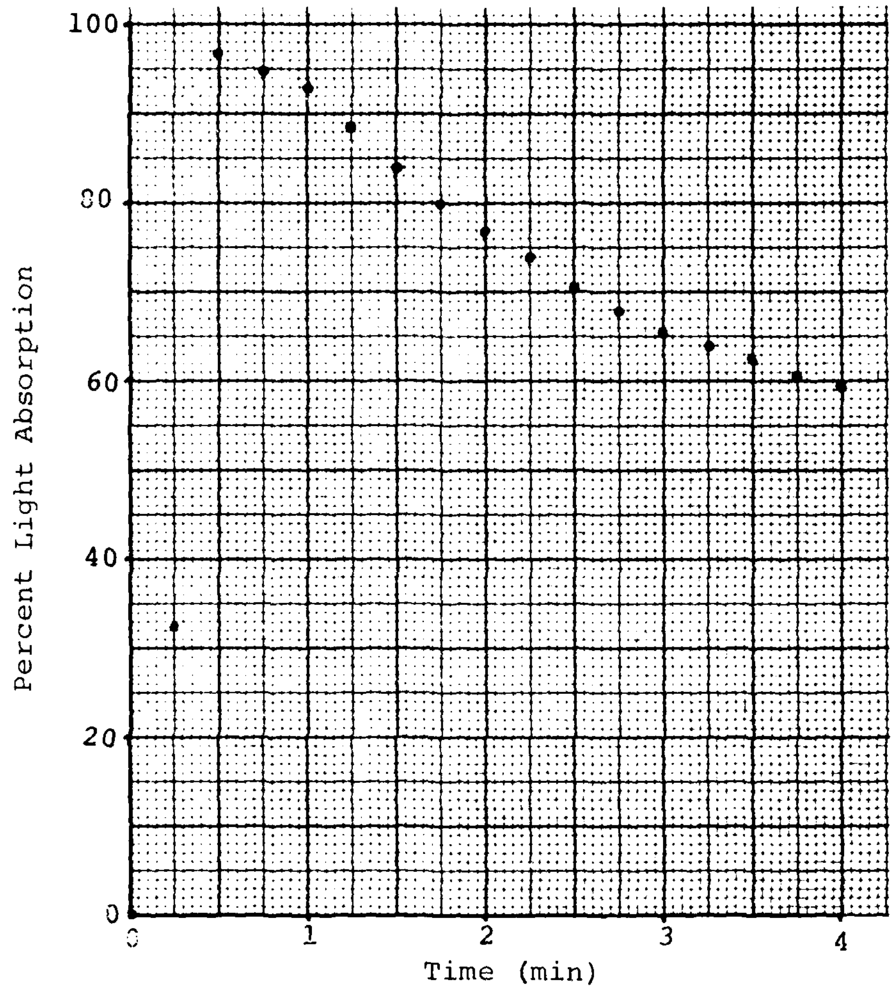


Figure 28. Light absorption versus time for Kevlar 49/epoxy with Tedlar backing, dry sample.

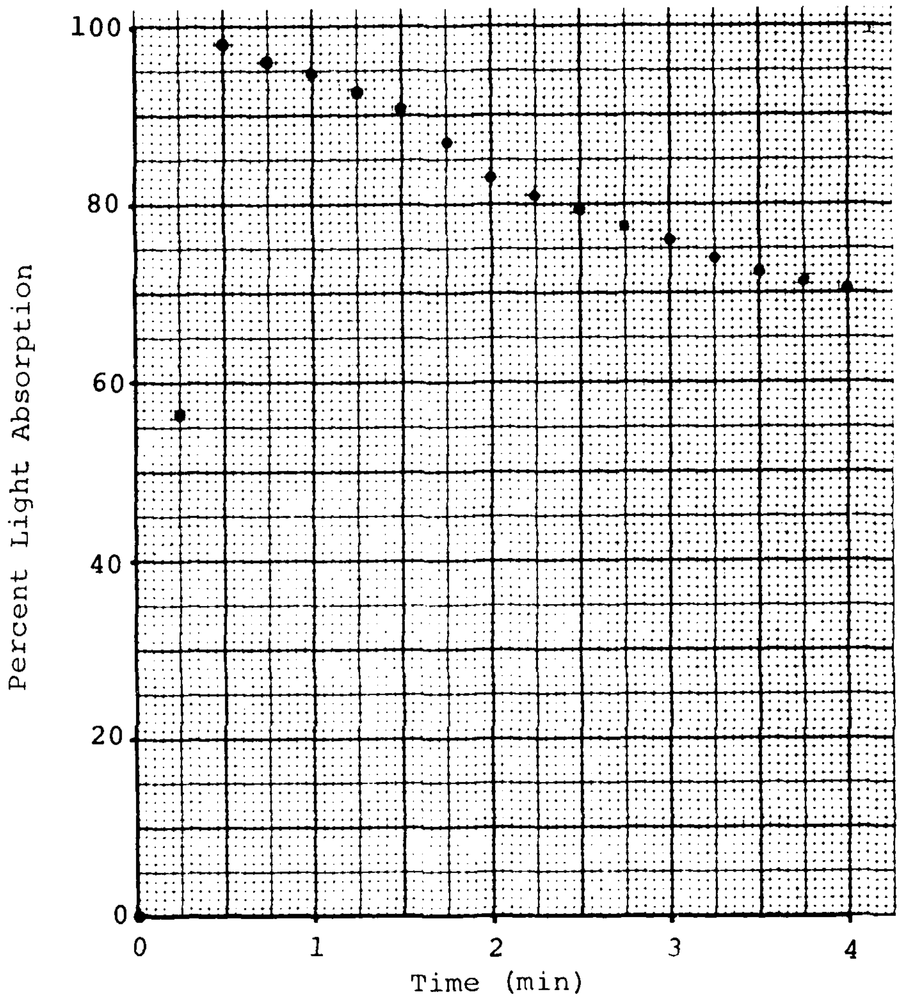


Figure 29. Light absorption versus time for Kevlar 49/epoxy with Tedlar backing, 30-second JP-4 fuel-soaked sample.

TABLE 6. LIGHT ABSORPTION VS. TIME TEST DATA (KEVLAR 49/EPOXY WITHOUT TEDLAR BACKING)

TIME (MIN: SEC)	Dry Specimen		Fuel-Soaked Specimen	
	Percent Light Absorption (Avg of 2 Trials)	Standard Deviation of the 2 Trials	Percent Light Absorption (Avg of 2 Trials)	Standard Deviation of the 2 Trials
0	0	0	0	0
0:15	55	1.4	71	16
0:30	96.1	2.4	95.6	2.0
0:45	94.5	2.2	93.6	2.5
1:00	91.5	3.3	89	4.5
1:15	87.5	5.2	84.5	3.5
1:30	83.5	4.9	81	2.8
1:45	80	5.7	77	2.8
2:00	76.5	6.4	73.5	2.1
2:15	73.5	6.4	70	1.4
2:30	71	7.1	67.5	0.7
2:45	69	7.1	65	0
3:00	67.5	7.8	63.5	0.7
3.15	66	8.5	62.5	0.7
3:30	65	8.5	61.5	0.7
3:45	64.5	9.2	61.5	0.7
4:00	64.5	9.2	61.5	0.7

TABLE 7. SUMMARY OF TEST DATA (KEVLAR 49/EPOXY WITHOUT TEDLAR BACKING)

	Dry Specimens	Fuel-Soaked Specimens
Area Under Curve	51.27 in.^{2}	49.49 in.^{2}
Smoke Density Rating	73.2%	70.7%

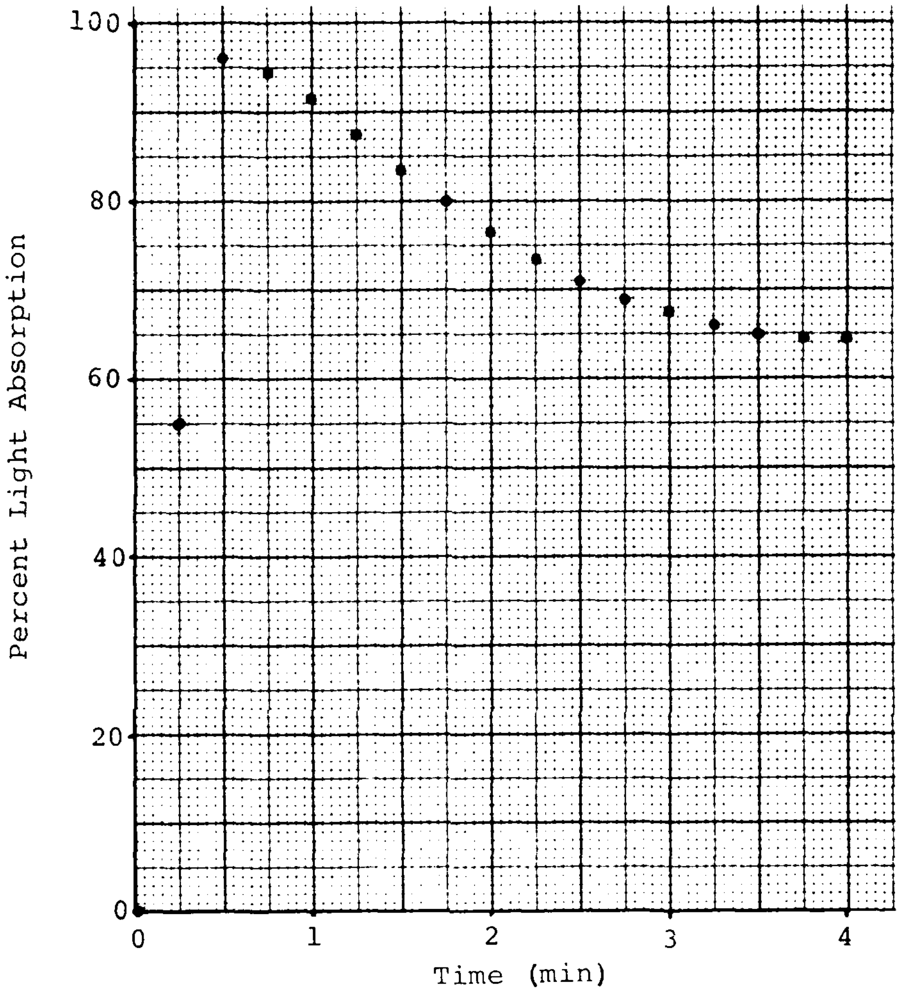


Figure 30. Light absorption versus time for Kevlar 49/epoxy without Tedlar backing, dry sample.

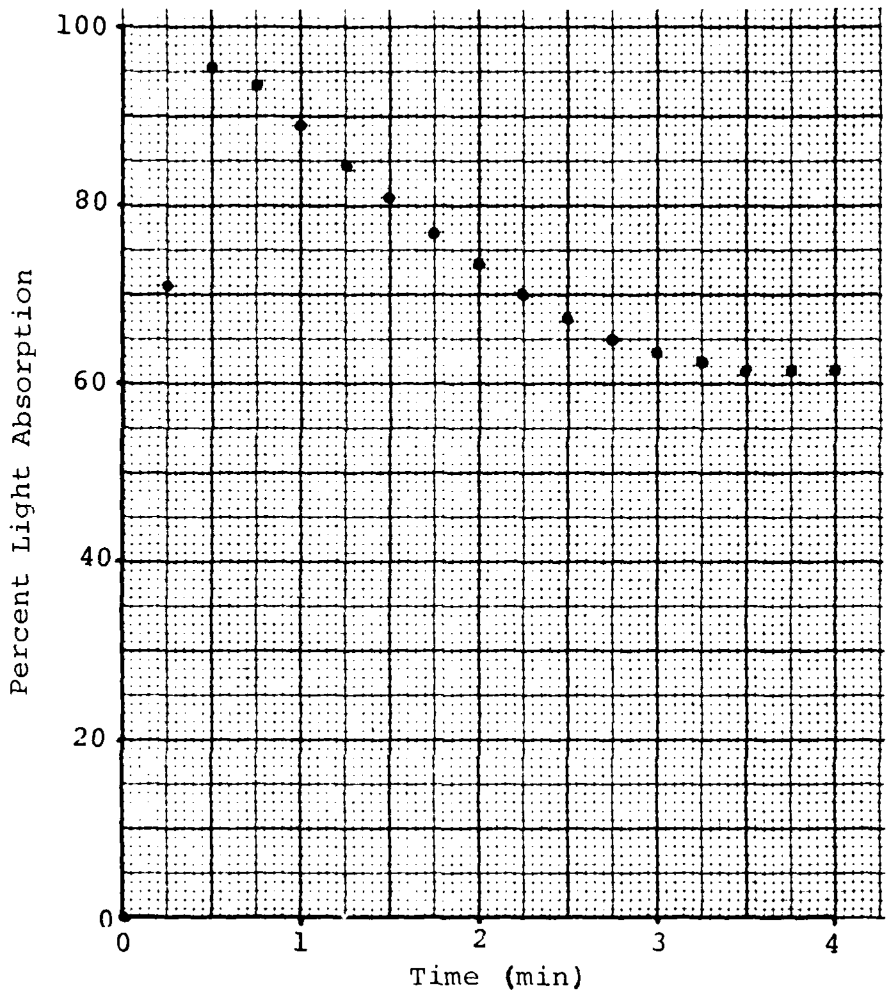


Figure 31. Light absorption versus time for Kevlar 49/epoxy without Tedlar backing, 30-second JP-4 fuel-soaked sample.

TABLE 8. LIGHT ABSORPTION VS. TIME TEST DATA (3501-6/AS GRAPHITE/EPOXY WITH NOMEX CORE)

TIME (MIN: SEC)	Dry Specimen		Fuel-Soaked Specimen	
	Percent Light Absorption (Avg of 4 Trials)	Standard Deviation of the 4 Trials	Percent Light Absorption (Avg of 3 Trials)	Standard Deviation of the 3 Trials
0	0	0	0	0
0:15	26.5	3.1	31.3	12.0
0:30	71.0	9.8	82.3	4.0
0:45	70.3	15.0	80.7	8.5
1:00	66.8	15.0	76.0	8.9
1:15	63.8	14.0	71.7	8.7
1:30	60.8	14.0	68.0	9.2
1:45	58.0	14.0	64.0	9.2
2:00	55.0	13.0	61.0	9.2
2:15	52.8	12.0	58.0	9.2
2:30	50.5	12.0	55.0	9.2
2:45	48.0	11.0	53.0	9.2
3:00	46.0	11.0	51.0	9.2
3:15	44.3	11.0	49.0	8.2
3:30	43.0	11.0	47.3	8.6
3:45	41.5	10.0	46.3	8.6
4:00	40.8	10.0	44.7	8.1

TABLE 9. SUMMARY OF TEST DATA (3501-6/AS GRAPHITE/EPOXY WITH NOMEX CORE)

	Dry Specimens	Fuel-Soaked Specimens
Area Under Curve	36.24 in.^{2}	40.75 in.^{2}
Smoke Density Rating	51.8%	58.2%

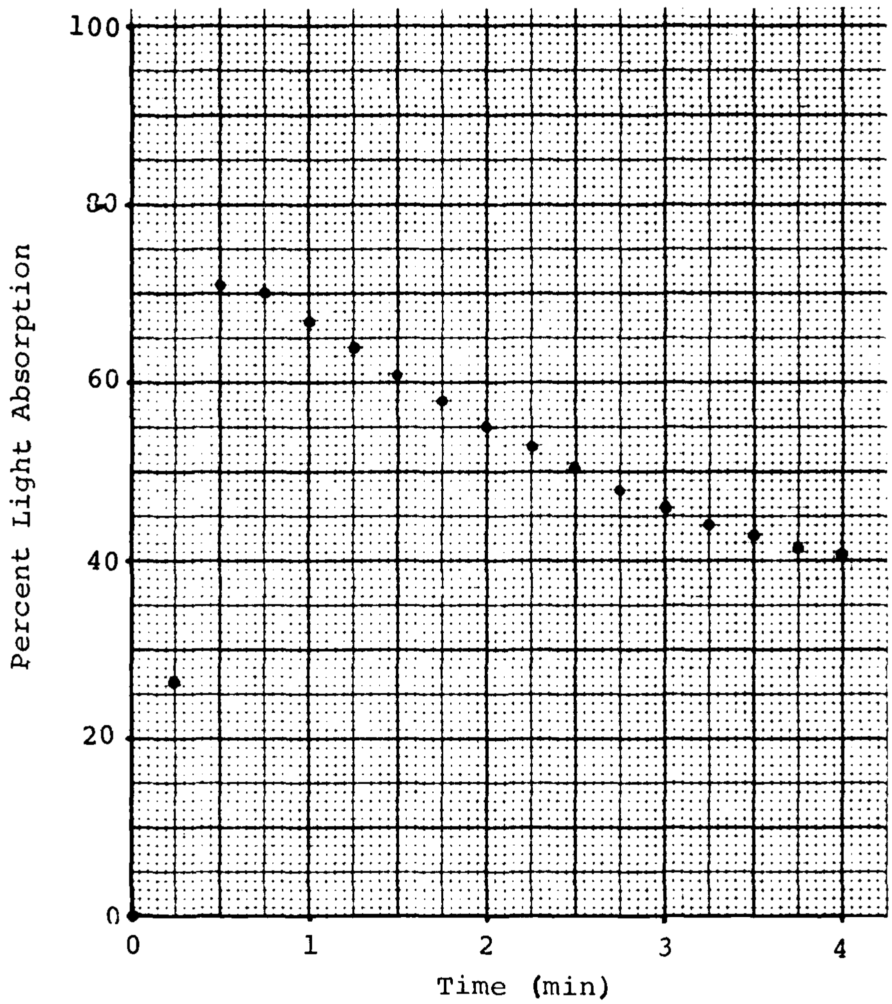


Figure 32. Light absorption versus time for 3501-6/AS graphite/epoxy with Nomex core, dry sample.

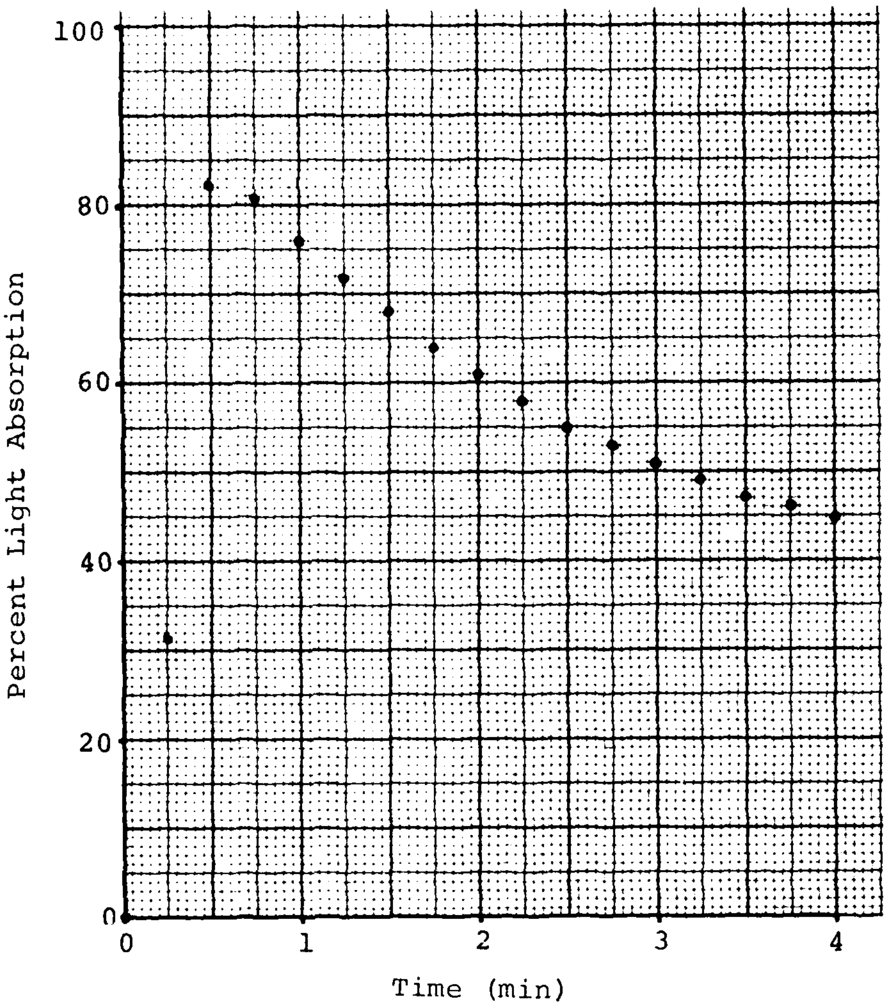


Figure 33. Light absorption versus time for 3501-6/AS graphite/epoxy with Nomex core JP-4 fuel-soaked sample.

TABLE 10. LIGHT ABSORPTION VS. TIME TEST DATA

	Percent Light Absorption			
TIME (MIN:SEC)	Dry Wood	Fuel-Soaked Wood	Dry ABS	Fuel-Soaked ABS
0	0	0	0	0
0:15	0	2	54.0	40.0
0:30	0	2	98.0	86.0
0:45	0	1	99.7	97.3
1:00	0	1	99.8	99.3
1:15	0	1	99.9	99.7
1:30	0	0	99.8	99.8
1:45	0	1	99.8	99.8
2:00	0	1	99.7	99.7
2:15	0	1	99.6	99.5
2:30	0	1	99.4	99.2
2:45	0	1	99.0	98.7
3:00	0	2	98.3	98.1
3:15	0	3	97.9	97.4
3:30	1	4	97.3	96.7
3:45	1	8	96.8	96.1
4:00	0	11	96.3	95.4

TABLE 11. SUMMARY OF TEST LATA (WOOD AND ABS)

	Wood	Fuel-Soaked Wood	ABS	Fuel-Soaked ABS
Area Under Curve	0.09 $in.^2$	1.47 $in.^2$	65.03 $in.^2$	63.96 $in.^2$
Smoke Density Rating	0.14%	2.1%	92.9%	91.4%

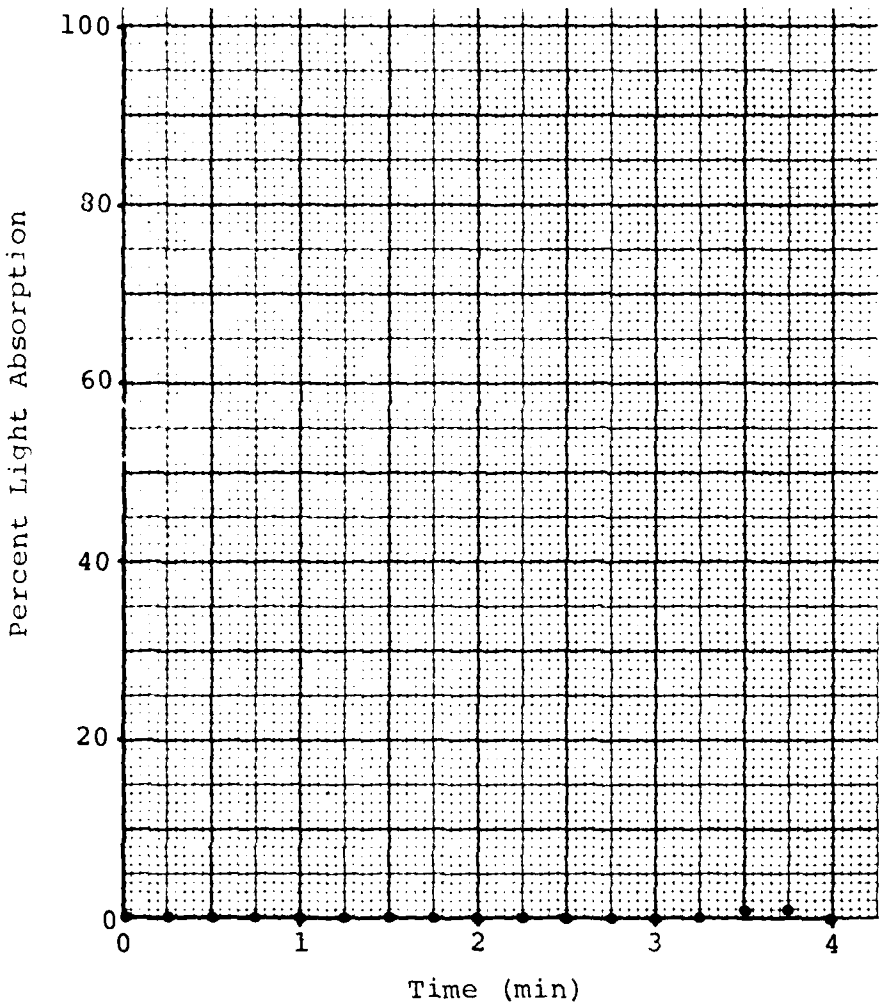


Figure 34. Light absorption versus time for 1/2-inch-thick plywood, dry sample.

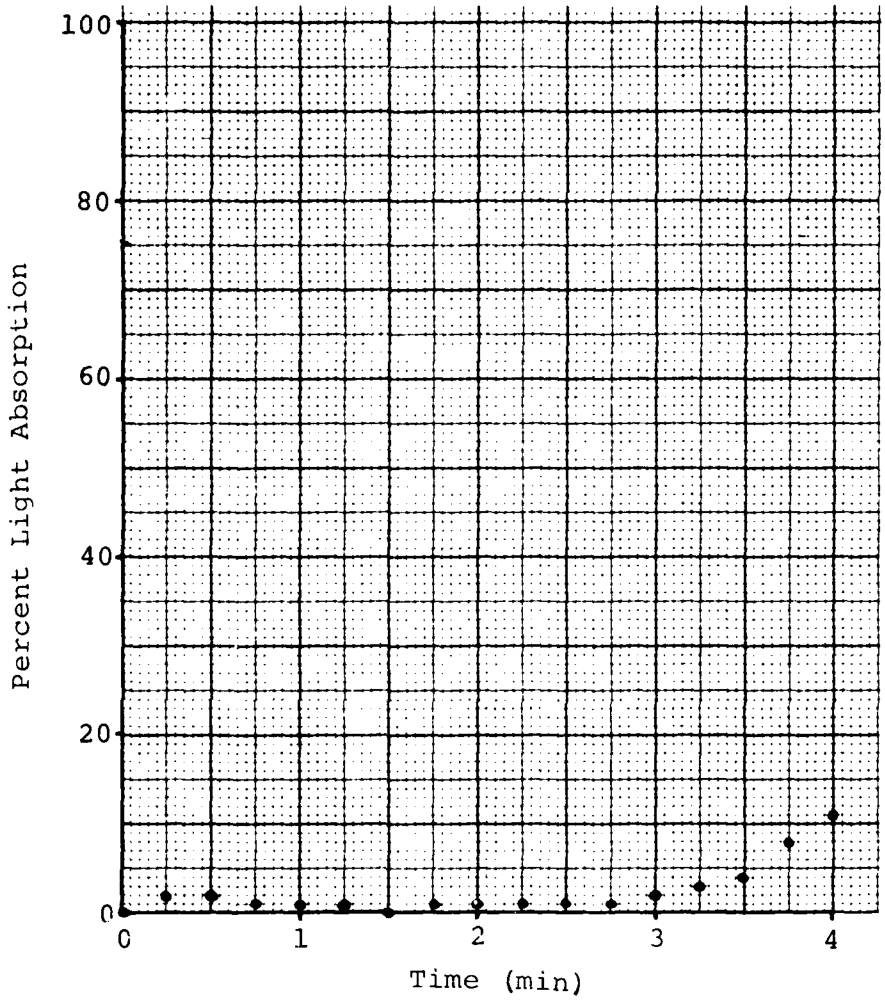


Figure 35. Light absorption versus time for 1/2-inch-thick plywood, 30-second JP-4 fuel-soaked sample.

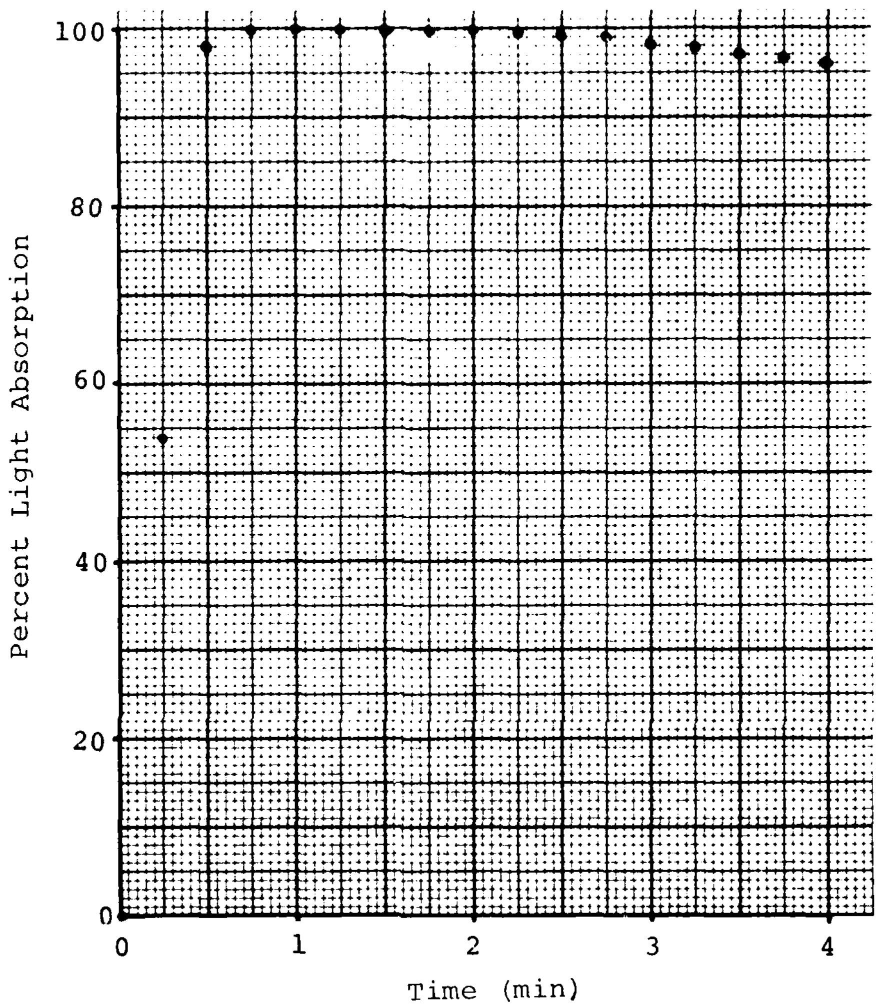


Figure 36. Light absorption versus time for ABS (Acrylonitrile-Butadiene-Styrene), dry sample.

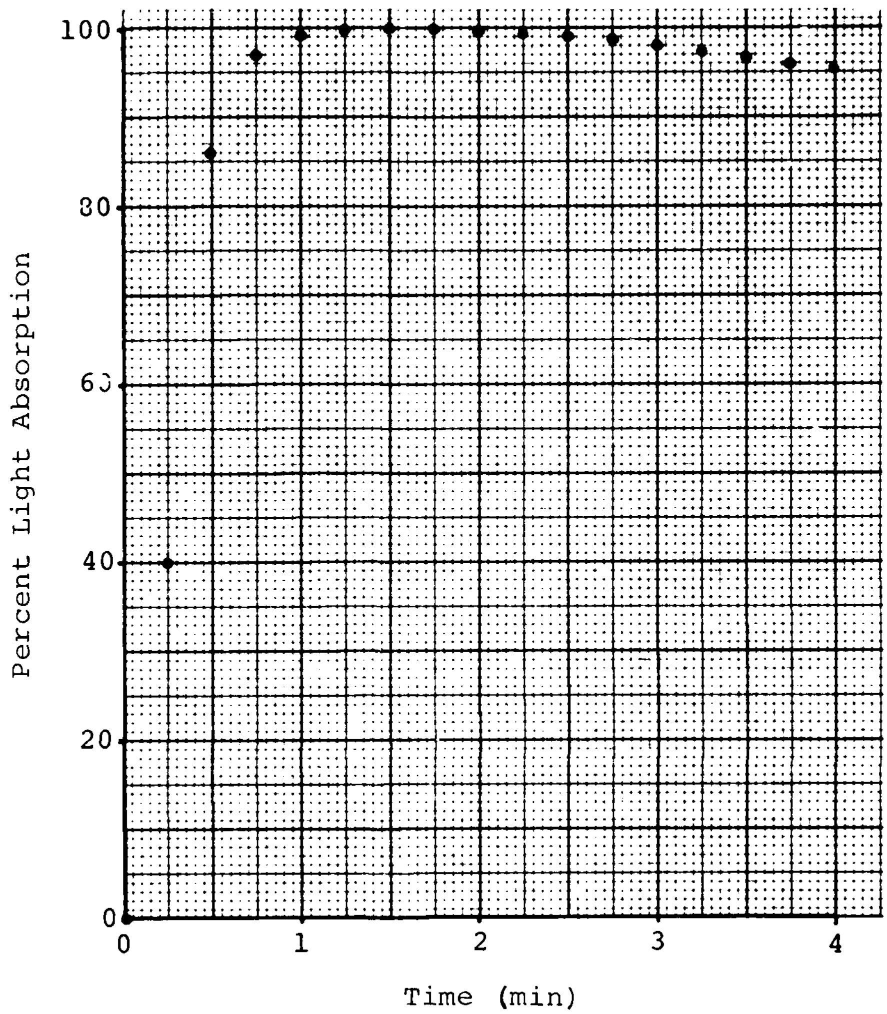


Figure 37. Light absorption versus time for ABS (Acrylonitrile Butadiene Styrene), 30-second JP-4 fuel-soaked sample.

TOXICITY TESTS

Purpose of Tests

The purpose of these tests was to develop methods for detecting toxic products released by burning composite materials as well as to evaluate the relative propensity of different materials to release these products.

The ignition, burning and gaseous products collection apparatus was the ASTM D 2843 chamber previously used for the measurement of smoke density. Analyses for toxic products were performed by precision gas indicating tubes, mass spectrometry and infrared spectrophotometry.

Description of the Specimens

The size of all specimens was 1 inch x 1 inch as shown in Figure 20. Specimen samples of the litter door and shell structure were tested in the dry and fuel-soaked conditions.

Litter Door Specimens

1. Kevlar/epoxy with and without Tedlar backing.

2. Tedlar backing was removed by grinding from the delivered specimens.

3. Specimens were yellow in appearance.

4. For consistency, all specimen samples were tested with the Tedlar side up and away from the flame.

Shell Structure Specimen. Graphite/epoxy (AS/3501-6) face sheets bonded to an inner Nomex core.

Control Specimens. For comparison, control specimens were tested in the dry condition only.

1. Graphite/epoxy (AS/3501-5A) laminate, 15 ply.

2. Acrylonitrile Butadiene Styrene (ABS) plastic, 1/4 inch thick.

3. Plywood, 1/2 inch thick.

Discussion

Summary of Methods. The ignition and burning of the specimens for the toxic products determination was accomplished with the United States Testing Company smoke density chamber previously used to determine smoke production properties. That work had shown that the maximum smoke density occurred after 30 seconds of heating by the propane flame. Thus, the procedure used for generating toxic products was direct heating by the propane flame for 30 seconds. Immediate sampling of the chamber for the generated toxic products was begun as soon as the burning sample self-extinguished.

Three sampling procedures were used for the generated toxic gases contained within the chamber. The first involved drawing small fixed quantities of gas through quantitative indicating tubes for certain specific gases such as nitrogen dioxide (NO_2), hydrogen cyanide (HCN), hydrogen sulfide (H_2S), sulfur dioxide (SO_2), and in a few cases nitric oxide (NO). The second sampling method used a 200 ml glass syringe for removal and storage of a gas sample for subsequent analysis by mass spectrometry. Finally, a direct transfer of the chamber atmosphere was made through a sampling manifold into a variable pathlength gas cell mounted in an infrared spectrophotometer. A photograph showing the testing chamber and infrared spectrophotometer is presented as Figure 38.

Gastec Precision Gas Detector System. The Gastec gas detector is a precision instrument that permits immediate, reliable determination of the concentrations of numerous gases and vapors. It consists of a piston-type volumetric pump into which direct-reading detector tubes are inserted. This equipment is shown in Figure 39. Analysis is based on chemical reaction of a reagent in the detector tubes with the gas or vapor sampled. Measurement is indicated by the length of stain or color appearing in the tubes.

The gas detector was particularly useful in this work for the measurement of NO, NO_2, HCN and H_2S whose concentration could not be measured by infrared spectrophotometry due to the large quantities of carbon dioxide (CO_2) and water vapor (H_2O) generated during the ignition and burning of the specimens.

Figure 38. Test chamber and spectrophotometer setup used in toxicity tests.

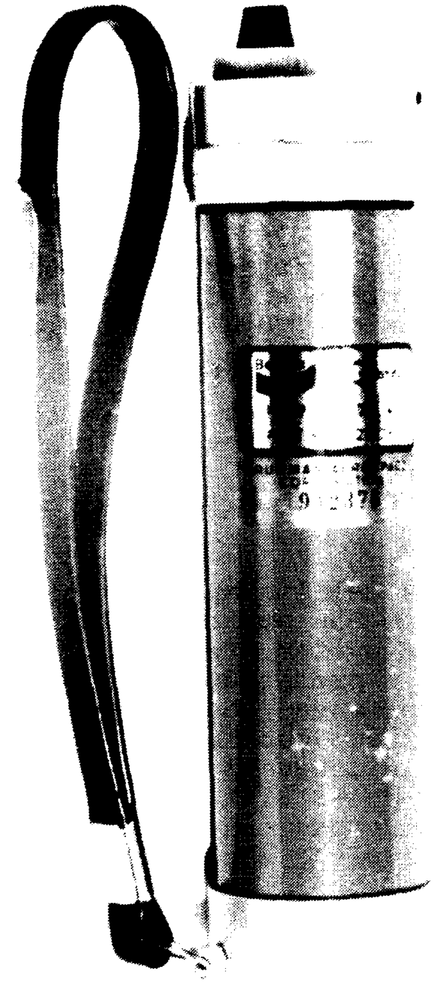


Figure 39. Gastech gas detector pump and typical tube used in analysis of combustion products.

Particular gas detector tubes can also be subject to interferences. In this work, only the SO_2 analysis by this technique presented a problem, because of the presence of significant concentrations of HCN. However, SO_2 was detectable and quantifiable by the infrared spectrophotometric method.

Mass Spectrometry. The 200-ml syringe samples were transferred to the batch inlet of a Hewlett-Packard 5930A mass spectrometer for quantitative analysis of any products present by conventional mass spectrometric techniques.

Infrared Spectrophotometry. Infrared spectrophotometry was used for the detection and quantification (where applicable) of carbon monoxide (CO), sulfur dioxide (SO_2), ammonia (NH_3), methane (CH_4), ethylene (C_2H_4), and other non-distinguishable hydrocarbons. A key to this technique is the sampling manifold which couples the variable pathlength gas cell mounted in the IR spectrometer with the smoke density chamber and also serves as a closed loop calibration system for the gas cell.

For a typical run, the gas cell, sampling manifold, and transfer line were isolated from the smoke density chamber by means of a valve, and the entire system was pumped down with a mechanical vacuum pump to a pressure of less than 1 torr (113 Pa). When this was accomplished, the specimen was placed in the chamber, the propane flame was ignited, and the sample burned for 30 seconds and allowed to self-extinguish. After the analysis with the gas detector tubes was completed and the sample for mass spectrometry was taken, the isolation valve was opened, allowing the sampling manifold and gas cell to be filled with the contents of the smoke density chamber. When the sampling manifold and gas cell reached atmospheric pressure, the system was again isolated with a valve, the circulating pump was started, and the infrared spectrum of the products was obtained.

Before any burning experiments were conducted, gas spectra of many of the anticipated products were obtained by introducing known quantities of the pure gases into the sampling manifold-gas cell combination. Calibration curves for the quantitative analysis of carbon monoxide, sulfur dioxide, methane, and ethylene were also prepared.

The instrumentation of other equipment used is listed below:

- Infrared Spectrophotometer: Perkin Elmer Corp., Model 621 (See Figure 40)

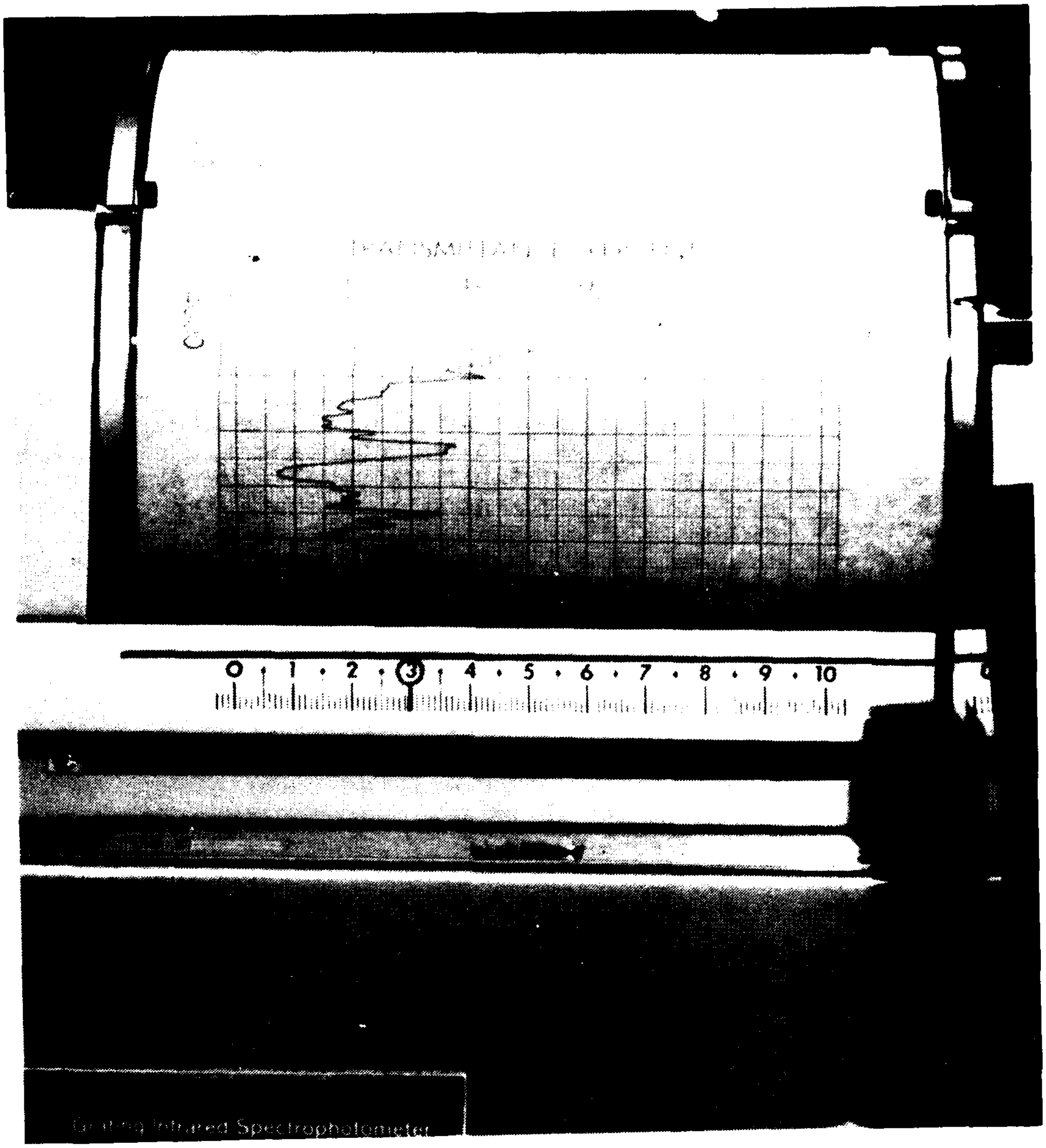


Figure 40. Spectrophotometer used in toxicity tests.

- Gas Cell: Wilks Variable Path 20-meter Gas Cell

- Cell Pathlength: 20.25 meters

- Circulating Pump: Wilks Scientific Corp., Model 106-0200 metal diaphragm pump

- Burn Chamber: United States Testing Company, 7700 Smoke Density Chamber

- Sampling Manifold: Constructed as described in Perkin Elmer publication Number 993-9236.

Test Results

The results of the analyses for toxic products are reported in Table 12. The results are a combination of the analyses obtained by the Gastec Gas detection tubes and those obtained by infrared techniques. No definitive results were obtained by mass spectrometry. Typical infrared spectra are presented in Figures 41 through 43.

Conclusions

- Toxic products are definitely generated by the ignition and burning of the composite materials studied during this testing.

- Carbon monoxide is the toxic product generated in the highest concentration. However, the lower levels of nitric oxide, nitrogen dioxide, hydrogen cyanide, and sulfur dioxide detected are also cause for concern because of their significantly lower threshold limit values (TLV).

- The presence of carbon monoxide in the combustion products is expected because of the oxygen-depleting burning process used. A real fire scenario would have a similar effect.

- Hydrogen cyanide and oxides of nitrogen are expected because of the presence of nitrogenous materials in the composites. The Kevlar composite has an amine-cured epoxy resin in addition to the aramid fiber. The shell structure contains the nylon-base honeycomb as well as an aniline-base resin and a sulfonated amine curing agent.

- The mechanism leading to the significant quantity of nitric oxide in the toxic products from the shell structure is unknown.

TABLE 12. DATA SUMMARY - ANALYSES OF TOXIC PRODUCTS[a,b]

SAMPLE	NO^c	$NO_2{}^c$	HCN^c	H_2S^c	$SO_2{}^d$	$NH_3{}^d$	$CH_4{}^d$	$C_2H_4{}^d$	CO^d	OTHERS[d,e]
Kevlar/Epoxy Without Tedlar	f	7	50	<5	<5	<5	18	8	260	
Kevlar/Epoxy Without Tedlar Fuel Soaked	f	12	35	<5	<5	<5	11	7	310	
Kevlar/Epoxy With Tedlar	f	8	35	<5	<5	<5	12	7	160	
Kevlar/Epoxy With Tedlar Fuel Soaked	<5	7	40	<5	<5	<5	15	8	280	
Shell Structure	90	3	25	<5	10	<5	<5	2	120	Nitrous Oxide (N_2O)[j]
Shell Structure Fuel Soaked	110	3	25	<5	10	<5	<5	4	150	Nitrous Oxide (N_2O)[j]
3501-5A/AS	f	g	h	i	15	<5	<5	2	90	Nitrous Oxide (N_2O)[j]
Acrylonitrile-Butadiene-Styrene (ABS)	f	2	60	<5	<5	<5	16	17	380	1,3 Butadiene (C_4H_6)[j]
Plywood	f	5	h	i	<5	<5	<5	2	100	

NOTES:

a - All results are expressed in parts per million (ppm) on a volume basis
b - All results are the average of duplicate runs except for the control specimens and the nitric oxide analyses of the helicopter composite structural materials
c - Analysis by Gastec Gas Detector Tube
d - Analysis by Infrared Spectroscopy
e - Hydrocarbons, which were not otherwise specified, were detected for all samples
f - No determination was made for nitric oxide with this specimen
g - No determination was made for nitrogen dioxide with this specimen
h - No determination was made for hydrogen cyanide with this specimen
i - No determination was made for hydrogen sulfide with this specimen
j - No attempt was made to quantify these gases.

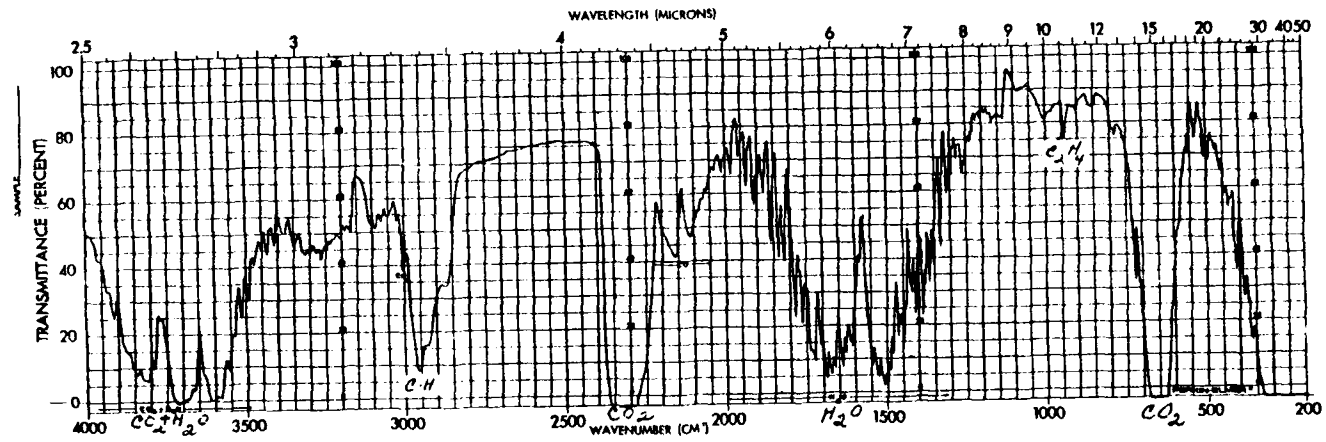


Figure 41. Infrared spectrum of gaseous products obtained from burning fuel-soaked litter door specimen.

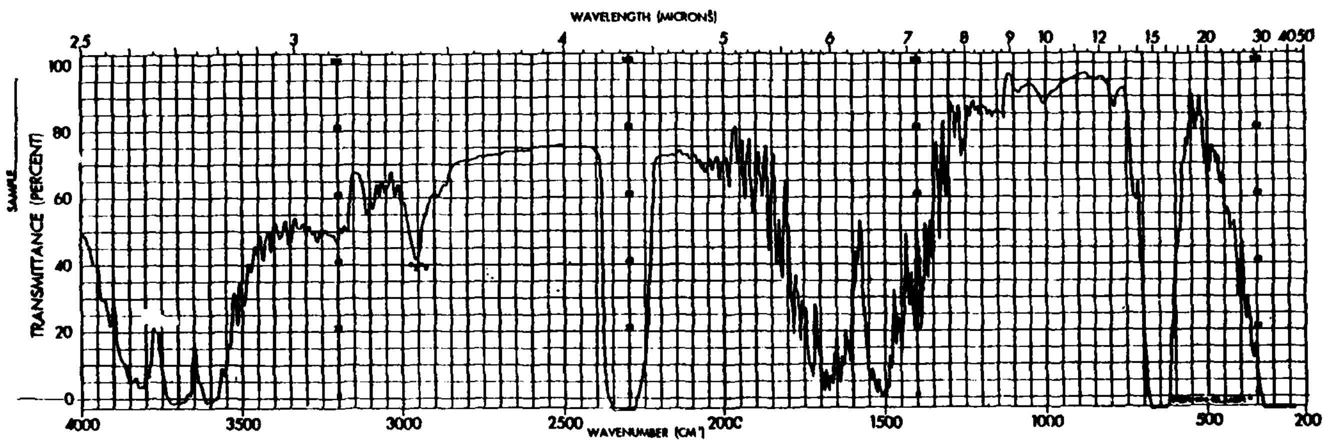


Figure 42. Infrared spectrum of gaseous products obtained from burning fuel-soaked fuselage shell structure specimen.

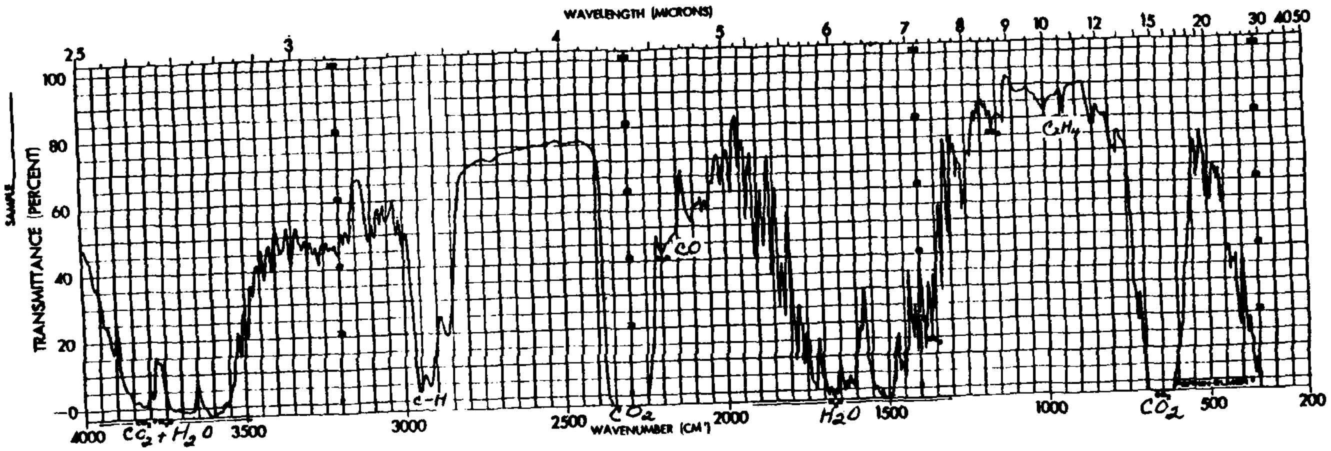


Figure 43. Infrared spectrum of gaseous products obtained from 30-second burning of the propane flame.

- The presence of sulfur dioxide in the toxic products from the shell honeycomb construction structure is undoubtedly due to the sulfonated amine curing agent in the graphite/epoxy face sheets.

- The presence of methane, ethylene, and nitrous oxide in the combustion products should not be cause for concern.

- No fluorinated products were detected with the methodology used. However, because of the extremely low threshold limit values for typical fluorinated combustion products (e.g., carbonyl fluoride), no conclusion can be reached regarding any hazards created by the presence of the Tedlar film on the Kevlar/epoxy sheet.

- The Tedlar film did inhibit the flame-spreading tendency of the Kevlar/epoxy sheet which apparently yielded slightly lower levels of generated toxic products.

- Ammonia and hydrogen sulfide were not detected in the generated combustion products.

Recommendations

- The presence of carbon dioxide and water vapor in the combustion products complicates the infrared analyses. A long pathlength reference cell, used to balance out these interfering species, can also be employed for the detection and quantification of more combustion products, especially resin pyrolysis products.

- Further improvement to the infrared analysis will be realized if a computerized infrared spectrometer is used. Spectrum subtraction techniques can then be employed for the detection and quantification of additional compounds.

- Separation and concentration techniques can be used prior to the mass spectrometry analysis so that additional products can be detected.

- Wet chemical procedures can be used for the determination of low levels of fluorinated combustion products.

- Future work should employ an NBS smoke chamber or similar device that uses a radiant, nonflaming heat source contained within a sealed burning chamber.

STRUCTURAL DEGRADATION TESTS

Purpose of Tests

The purpose of these tests was to establish the extent of degradation of the structure when it is exposed to fire. This degradation was qualitatively determined by the time-to-failure of test specimens subjected to static load and fire.

Description of Test Specimens

Flat-test panels were prepared from laminates identical in material and orientaton to the ballistic test articles.

Litter Door Specimens. Test specimens simulating the litter door were made from 3-inch x 16-inch three-ply laminates of Hercel F185/Kevlar 49-281 weave prepreg cloth. Ply orientations were 0°/45°/0°. Fiberglass and/or aluminum doublers were bonded to each end of each specimen and 0.500-inch diameter holes were drilled on the specimen centerline, 1.1 inches from each end.

Shell Structure Specimens. Flat test specimens, 3 inches x 16 inches, were made from the same materials as the shell structure ballistic test article. The face sheets were two-ply, 0°/45° laminates of Fiberite T300 cloth and were bonded to 0.50-inch-thick Nomex core. The core was potted on the ends with 934 compound to support aluminum doublers with 0.500-inch holes similar to the Kevlar/epoxy specimens above.

Test Method

The tests were conducted in accordance with the approved test plan. Fuel-soaked specimens were immersed in JP-4 for one hour immediately prior to the test. The test setup for the structural degradaton testing is shown in Figures 44 and 45. In Figure 44, the test specimen is shown ready for test. At each side of the specimen are steel flame shields to prevent flow of the flame around the edges of the sample. In Figure 45, the gas burner is shown in place. A chromel-alumel thermocouple is suspended in front of the test specimen for monitoring flame temperature. With the burner removed from the specimen, the flame was adjusted to 2000°F ±10°F. The burner was then moved in place in front of the specimen and the timer was started. The timer was stopped when failure occurred. Loads were applied with a calibrated hydraulic cylinder and monitored using a calibrated pressure gauge.

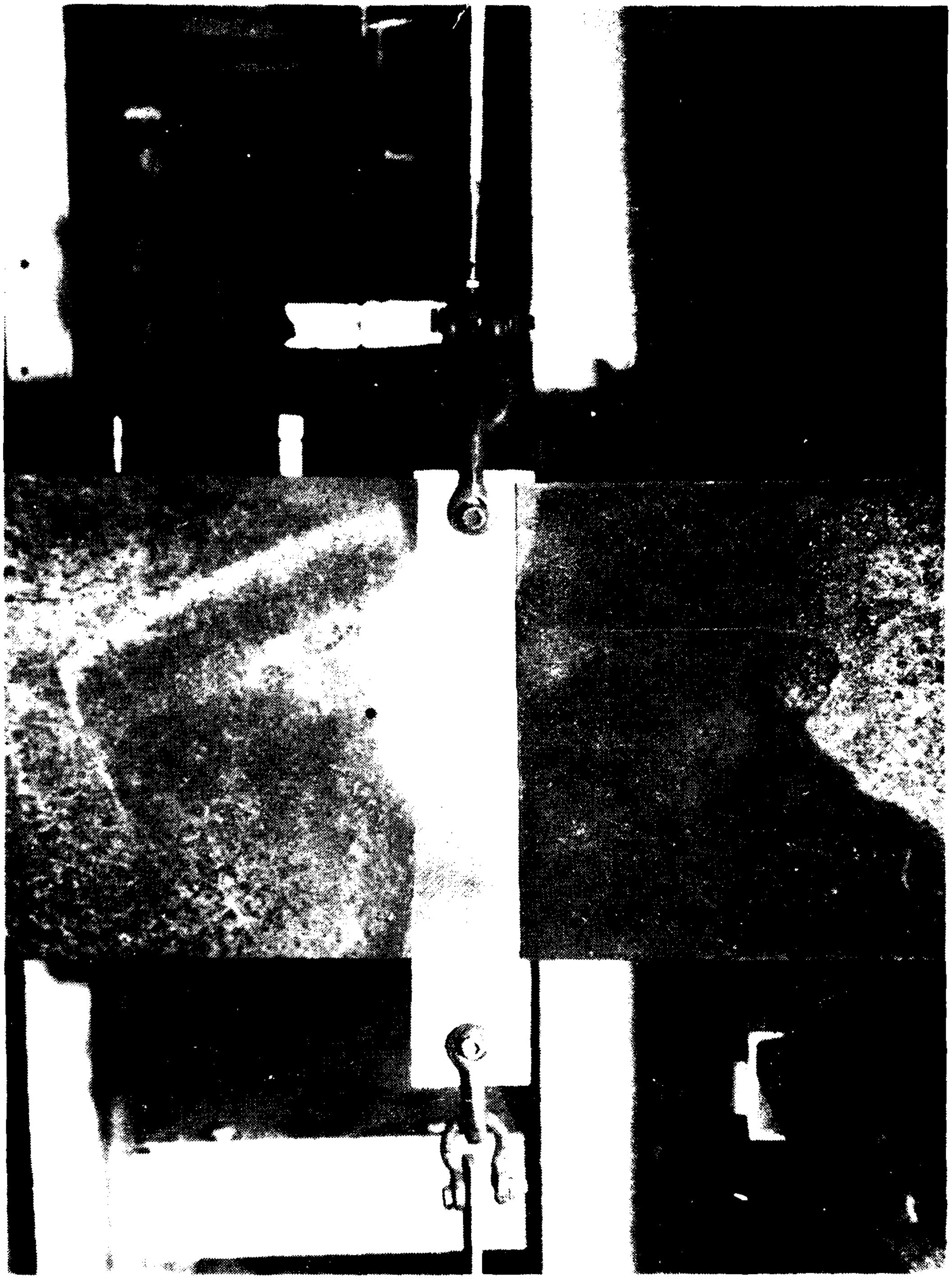


Figure 44. Structural degradation test specimen ready for test.

AD-A104 757 BELL HELICOPTER TEXTRON FORT WORTH TX F/G 13/12
INVESTIGATION OF THE STRUCTURAL DEGRADATION AND PERSONNEL HAZAR--ETC(U)
AUG 81 R J SCHILTZ DAAK51-79-C-0009

UNCLASSIFIED USAAVRADCOM-TR-81-D-16 NL

2 OF 2
AD
A104 757

END
DATE
FILMED
10-81
DTIC

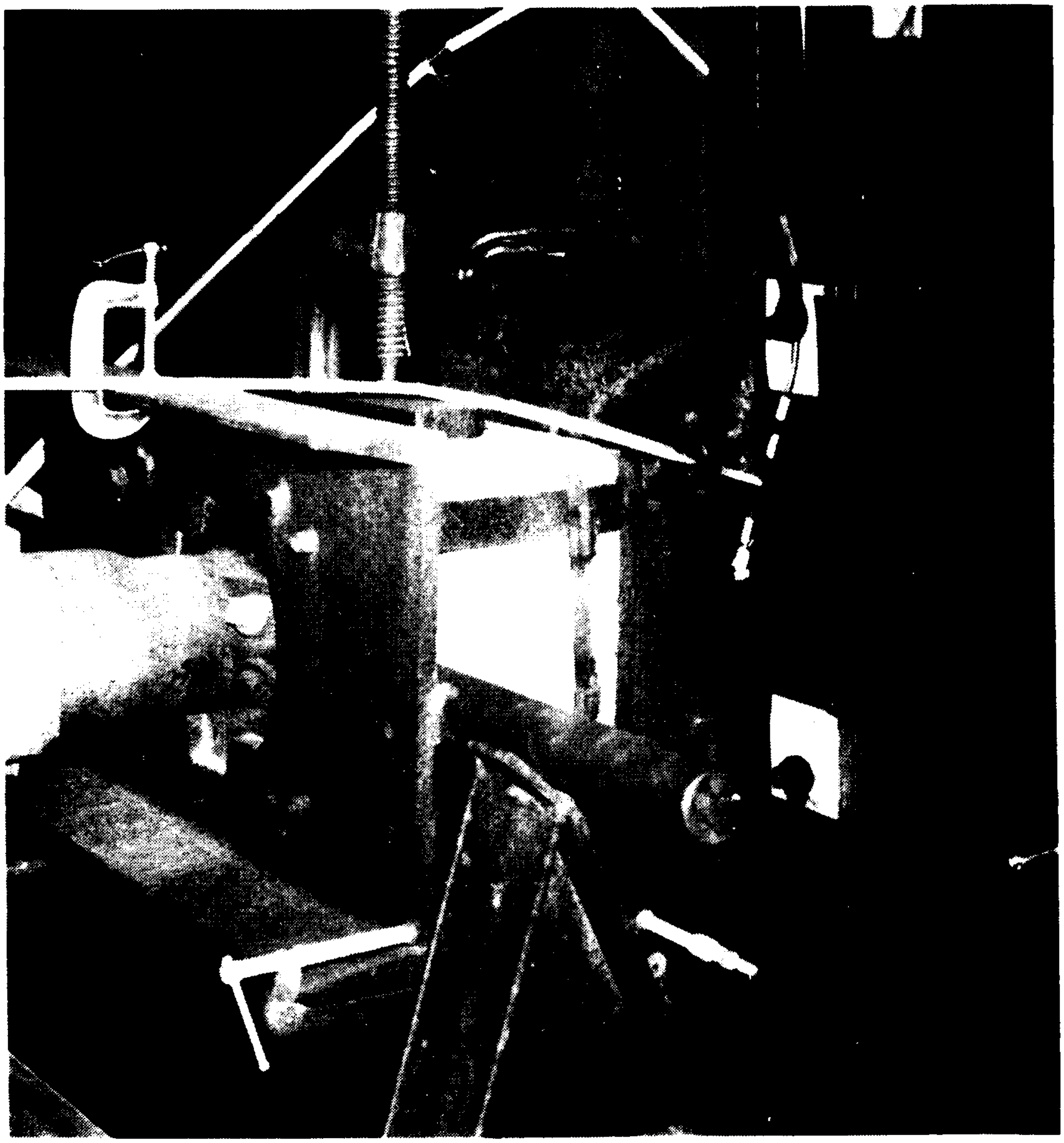


Figure 45. Burner in place for structural degradation test.

Test Results

Test results for all specimens are presented in Table 13 and in Figure 46.

Litter Door Specimens. For the Kevlar specimens, the average static load to failure (100 percent load) was 7000 pounds. Structural degradation tests (time to failure when exposed to flame) were conducted under constant axial loads of 80, 60, 40, and 20 percent. As may be seen in Figure 46, the fuel-soaked specimens exhibited uniformly shorter times to failure than the dry specimens.

Shell Structure Specimens. For the graphite/epoxy skin Nomex core sandwich specimens, the average static load to failure (100 percent load) was 4940 pounds. Structural degradation tests (time to failure when exposed to flame) were conducted under constant axial loads of 80, 60, 40, and 20 percent. As may be seen in Figure 46, the response of these specimens to the load/flame environment was not as simple as the corresponding response of the Kevlar/epoxy laminate specimens. The dry shell specimens were relatively short-lived at higher load levels compared to the lower load levels. The wet specimens, however, showed no significantly shorter times to failure at loads of 80, 60 or 40 percent. At 20 percent loads, the wet specimens lasted almost three times longer than the dry specimens. The anomaly appears to have been caused by the soaking. Although the edges of the sandwich had been sealed during full immersion soaking, fuel did penetrate through the skins (this was a two-ply fabric) into the Nomex core cells. Some specimens actually "sloshed" when shaken. This liquid core apparently provided some cooling effect at all load levels and, most significantly, at the 20 percent level prolonged the life of the specimen during test.

Test Article Disposition

The test specimens were photographed after testing was completed. These photographs are presented in Figures 47 through 50. The specimens were then given to the ATL Structures Technical Area for reference.

TABLE 13. RESULTS FROM STRUCTURAL DEGRADATION TESTS

Material Condition	Load Level[a] 20%	40%	60%	80%	100%
Kevlar/epoxy, dry[d]	20, 23	16, 17	10, 12	5, 6	0
Kevlar/epoxy, soaked 2[b]	17, -	9, 10	6, -	2, 3	0
Graphite/epoxy sandwich, dry[e]	60, 80	42, 58	4, 12	6, 1.7	0
Graphite/epoxy sandwich, soaked b, c, e	175, 210	27, 48	16, 28	3, 11	0

NOTES:

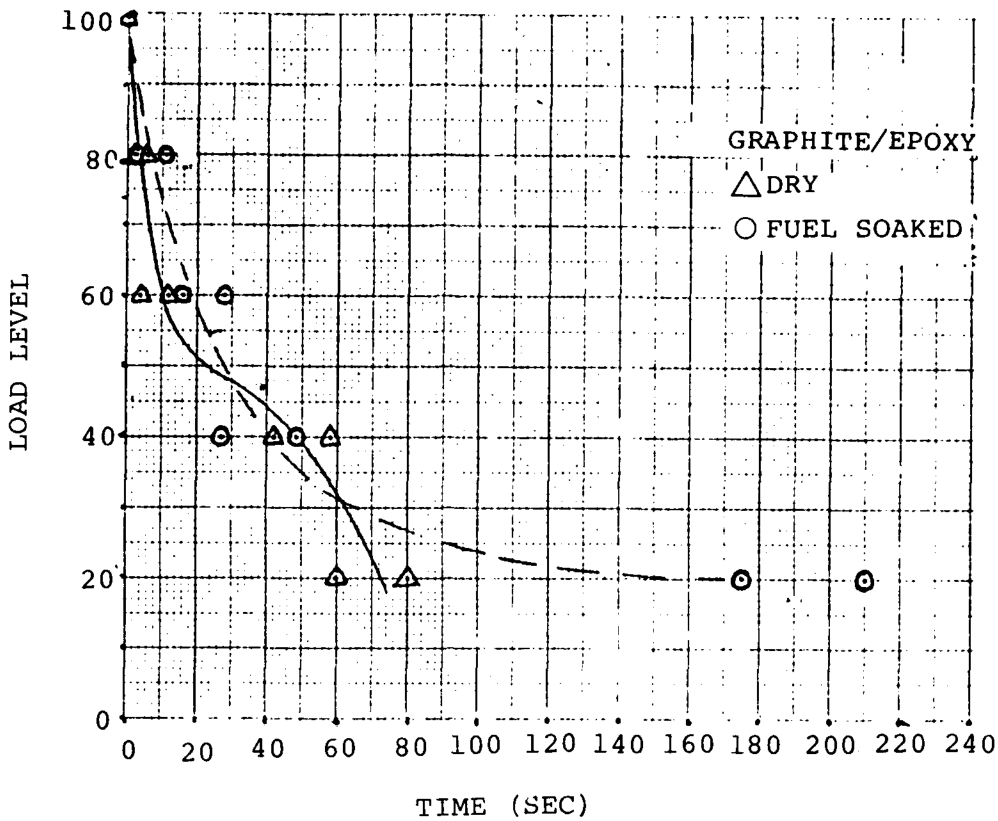
a. Tabulated data are times to failure (sec) for axial specimens subjected to a 2000°F flame while under the indicated steady axial load.

b. Fuel-soaked specimens were immersed in JP-4 fuel for 1 hour at room temperature prior to test.

c The graphite/epoxy sandwich panels partially filled with JP-4 during the 1-hour fuel soak prior to testing. It is not clear whether this fuel penetrated through the skins or through the core walls. At any rate, there was an obvious cooling of the surface during the lower stress level tests that resulted in longer test times.

d. Kevlar/epoxy static test data were 6540, 7720, and 6840 pounds. Average = 7000 pounds. Tests at 80 percent (5600 pounds), 60 percent (4200 pounds), 40 percent (2800 pounds), and 20 percent (1400 pounds).

e. Graphite/epoxy static test data were 4190, 5860, and 4760 pounds. Average = 4940 pounds. Tests at 80 percent (3952 pounds), 60 percent (2964 pounds), 40 percent (1976 pounds), and 20 percent (988 pounds).



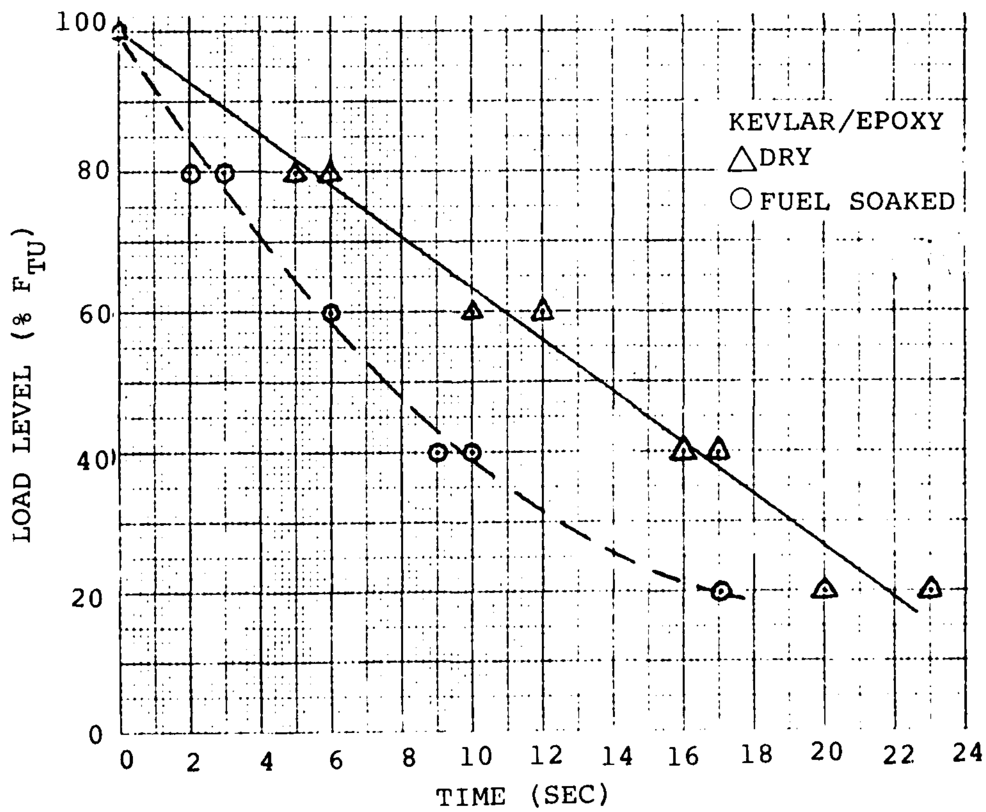


Figure 46. Results from structural degradation tests.

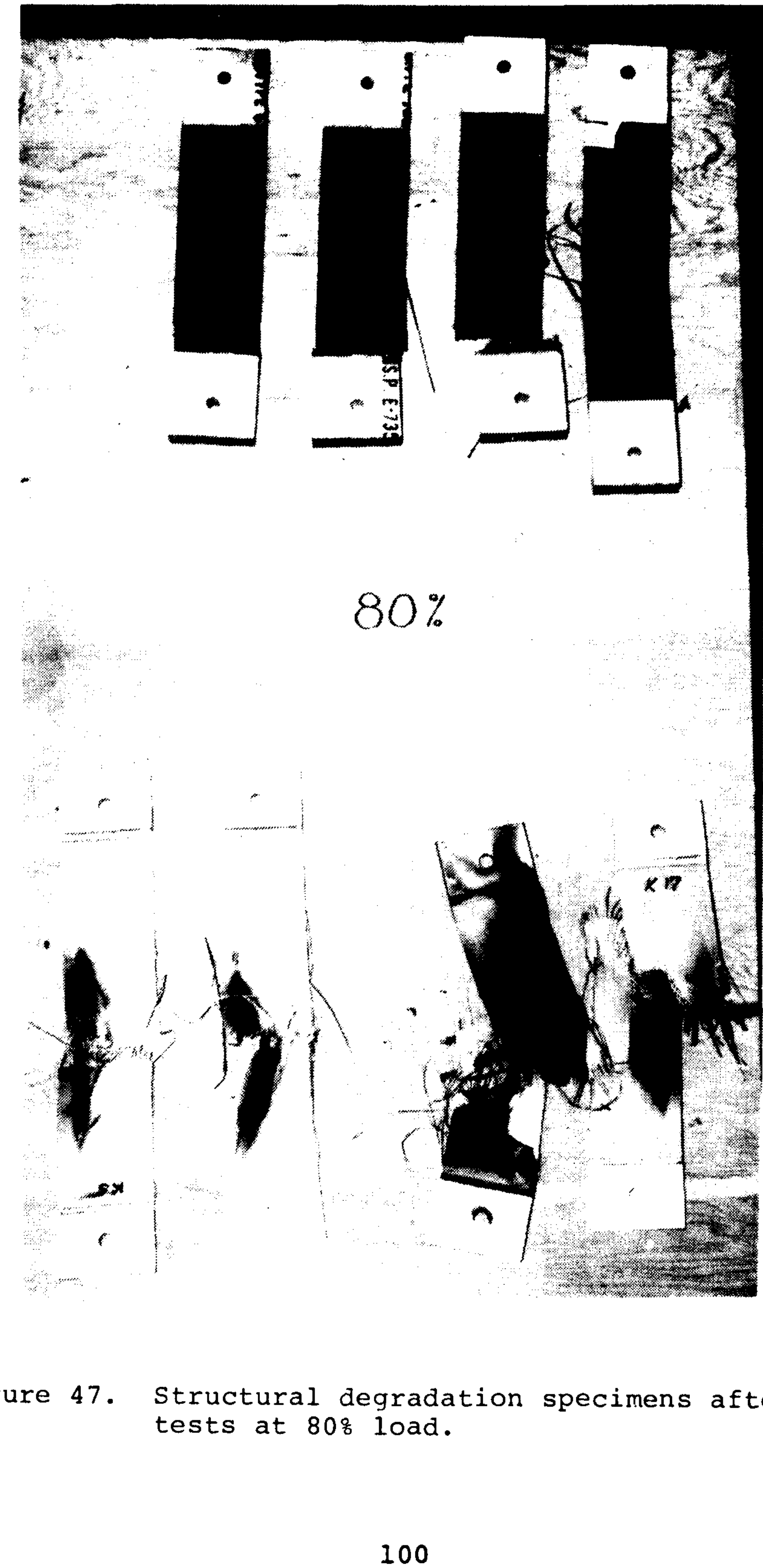


Figure 47. Structural degradation specimens after tests at 80% load.

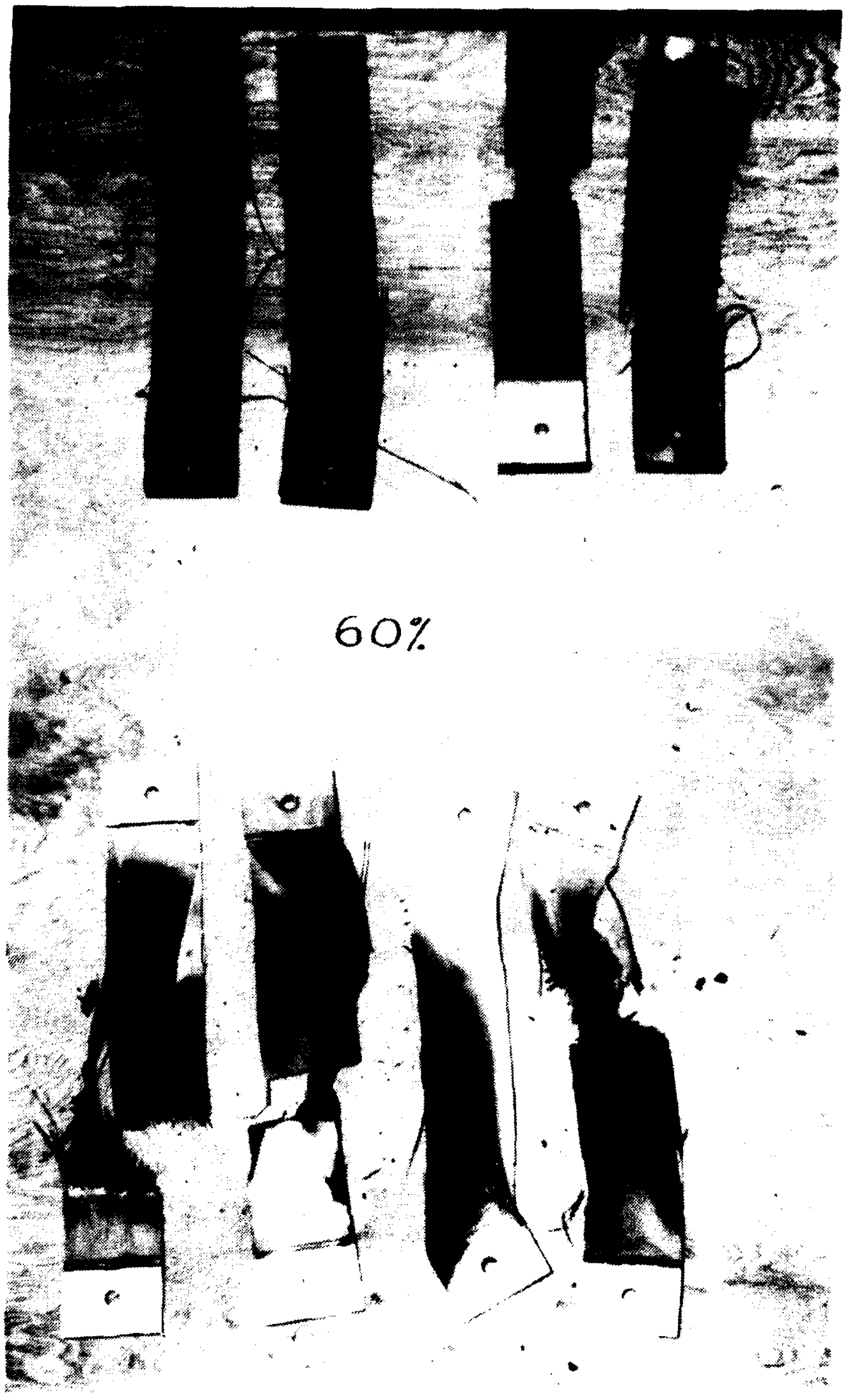


Figure 48. Structural degradation specimens after tests at 60% load.

Figure 49. Structural degradation specimens after tests at 40% load.

Figure 50. Structural degradation specimens after tests at 20% load.

4. DESIGN CRITERIA

During the course of this program, tests were conducted on airframe components constructed of Kevlar/epoxy and graphite/epoxy in an effort to gain an insight into the materials' behavior when exposed to a high temperature environment. The specific tests conducted measured the flammability of the materials when they are exposed to ballistic damage from an incendiary projectile; the smoke and toxicity generated by the materials when they are exposed to an open flame; and the structural degradation imparted to the materials when they are subjected to a flame of high intensity. The general flammability of the materials (i.e., the ease of ignition, flame spread rate, heat release rate, and flash fire potential) was not a topic of interest during this investigation. Some design guidelines may be postulated as a result of the test program and the literature survey.

Based on the results of the ballistic tests, wherein the composite materials did not ignite when impacted by an incendiary projectile, there does not appear to be any necessity for guidelines or criteria that might restrict the use of composite material. Evidently, the heat imparted by an incendiary projectile does not raise the temperature of the composite materials to a degree sufficient to cause ignition.

The data collected from the smoke and toxicity tests indicate that, unlike metal structure, composite materials do burn and in the process give off toxic gases and smoke. This is particularly true of their resin systems, many of which are petroleum based. However, a criterion for the application of composites in airframe construction, which is dependent on the smoke and toxicity behavior of the material, is difficult to derive for several reasons. First, there is disagreement among the investigators in the field, the various government agencies, and the regulatory bodies as to which test or tests accurately measure the smoke and toxicity response of the materials. Second, part of this difficulty may lie in the fact that many of the testing procedures were developed for evaluating materials in the building construction or mass transit industries and, as such, have to be adapted for aerospace use. For instance, the National Bureau of Standards (NBS) smoke density test uses the NFPA Standard No. 256-76, "Standard Test Method for Measuring the Smoke Generated by Solid Materials," published by the National Fire Protection Association. Finally, the results of the toxicity tests are difficult to analyze because of the synergistic effects of the different gas combinations.

For these reasons, the designer is faced with a dilemma when confronted with a material choice based on smoke emission and toxicity. At present, it appears that composite materials should be capable of satisfying the optical density standards of 100 and 200 after respective time intervals of 90 seconds and 4 minutes from the start of the tests as proposed by the FAA and the Urban Mass Transportation Administration (UMTA). These optical density readings should be measured during tests conducted in an NBS smoke chamber. Since the tests conducted during this program used the procedures described in ASTM D2843, a direct correlation with the NBS standards is not possible.

A standard or criterion for toxicity requires additional testing, possibly with animals, to determine the effects or the byproducts of combustion. Testing conducted in this program produced carbon monoxide and hydrogen cyanide as the primary byproducts, with lower levels of nitric oxide, nitrogen dioxide, and sulfur dioxide. All of these chemical agents are hazardous and represent a threat to human habitation. The question that is not answered is the level of ingestion required to incapacitate a human being. Since many of these byproducts are also evident during the burning of commonly used aircraft interior materials, such as nylon, wool, polyvinyl chloride, modacrylic, polyimide, and urethane (flame retarded), to name a few, it is evident that the use of composite materials will not pose an extraordinary hazard.

The final set of tests measured the structural degradation of composite materials when they were subjected to a 2000°F flame while being loaded axially. A flame of this intensity is usually associated with an engine compartment fire. In this case, a designer should provide multiple load paths around prospective areas that could be subjected to an intense fire. Additionally, a fire-resistant resin system such as polyimide should be used to retard damage and to improve structural capability. These are the same design philosophies as are applied to metal structures where redundancy is provided and titanium is used as a fire shield. Therefore, changing materials does not necessitate an adjustment of the design approach.

In summary:

1. Requirements for a design criterion restricting composite materials because of flammability due to an impact from an incendiary projectile are not necessary.

2. A criterion for smoke emission should follow the FAA and UMTA guidelines.

3. A requirement for a toxicity criterion awaits further testing and agreement from the regulators, manufacturers, and users.

4. Requirements for structural degradation of composites should use the same philosophy as is applied to metal structures.

5. ENCLOSURE FIRE SIMULATION

The Dayton aircraft cabin fire simulation program (DACFIR-2) has been developed to assess the smoke, heat, and toxic gas accumulation within an aircraft cabin subjected to fire, within a period representative of postcrash emergency evacuation time. The model provides a means of tracking the development of the fire and the changes in cabin environment with time. The required input to the simulation program includes a description of the cabin geometry (dimensions, location of interior surfaces, materials), the ignition scenario (initial fire size and location, ventilation conditions) and a description of the properties of the materials as measured by laboratory scale flammability and toxicity tests (flame spread rates, heat, smoke, gas release rates).

The computer program employs a technique of approximating the distribution of burning or smoldering regions on combustible materials by dividing the surface of the material into 6-inch-square area elements. The combustion behavior of a material is modeled by allowing the area elements to exist in one of seven discrete states. The four primary states are the following: virgin (the original unignited condition), smoldering (nonflaming thermal degradation), flaming (burning with open flaming), or charred (burned-out or inert). The other three states are intermediate states, representing the transition to or from one of the four primary states. Fire ignition; flame spread of heat, smoke, and toxic combustion products; and the eventual extinction of a fire are all predicted by specifying times of transitions between the four primary states and by specifying flame spread rates. Transition times; flame spread rates; and the smoke, heat, and toxic gas release rates are assumed to be known as functions of imposed heat flux from laboratory measurements on the specific materials and assemblies of an aircraft cabin interior. Smoke and toxic gas concentrations within the cabin section of the fire origin are computed by a one-dimensional, dynamic, stratified model of the cabin atmosphere, which includes buoyancy driven flow out of the cabin section through one or more doorways.

The output of the program includes histories of composition and temperature of the cabin atmosphere, oxygen consumption, the location of the regions where the fire spreads, and the size of the damage. Finally, an updated and improved version of the program, designated DACFIR-3, will be forthcoming in the near future.

This computer program, which was requested from the University of Dayton Research Institute, was received on 19 September

1980. The package included a tape (a track, 1600 BPI), a Fortran source code of the computer program, and a sample data set "26P". The user's guide was sent separately. The program was written in Fortran V, which was not compatible with the GAC or ATL computing facilities. Changes were made in the code to enable the program to be run on GAC's Fortran IV computer, and successful runs were made. Some round-off errors were noted in the output of this modified program, but these discrepancies were small. The program is considered operational and the demonstration on an ATL terminal followed the Task III briefing at ATL.

6. CONCLUSIONS AND RECOMMENDATIONS

This program has provided an introductory investigation into important areas of interest when considering exposure of composite structural materials to fire and explosions. Recommendations based on this study are presented below.

TECHNOLOGY SURVEY

The technology survey in this program was actively pursued through October 1979. It became obvious during the formulation of design criteria that some important documents have recently become available. It is recommended, therefore, that some effort be undertaken to update and continue the technology survey until the technical questions that fostered this work are settled.

BALLISTIC VULNERABILITY

Based on the tests reported herein, no further ballistic testing of composite structural components for the purpose of determining initiation of combustion is recommended. There is no necessity for guidelines or criteria that would restrict the use of composite materials.

SMOKE AND TOXICITY

Composite materials burn and give off smoke and toxic gases. However, lack of agreement among investigators and agencies as to which tests are most informative and the lack of tests developed for aerospace materials and conditions have made it impossible to formulate definitive smoke or toxicity criteria. Smoke tests using ASTM D2843 chambers are not even qualitatively correlatable to NBS chamber tests. Current UMTA and FAA guidelines have led to more frequent use of the NBS chamber test. It is recommended that further testing be performed using the NBS chamber to evaluate materials currently used or proposed for use in U. S. Army helicopter programs. It may be best to characterize the behavior of resins and fibers separately as useful information. These data should be analyzed and kept in a data file for access and as a basis for future criteria decisions.

In the case of toxicity testing, it is not sufficient to determine the products of combustion only. The questions that are unanswered by these tests are how much of each toxic product is allowable and how the presence of one toxic substance affects the response of individuals to other toxic substances. The study of these questions is in its infancy, and no one is willing at this time to devise design criteria

with quantifiable guidelines. Much more work must be done in this area, both in identification of toxic products and in understanding their effect on people.

STRUCTURAL DEGRADATION

Structural degradation of composite materials must be measured and ranked in order to provide data for future design decisions. In addition, flammability of the materials should be determined and included in the data base. Thought must be given to providing redundant load paths in locations that historically have been subject to fires. Systems for fire detection and automatic extinguishing systems should be considered for use in areas not observable by the pilot. For use in design analysis, the expectable flame temperatures due to various fuels, mists, and vapors should be made available with the other data in this program. These same considerations should be made for metal structures. Special guidelines are not necessary for composite structures.